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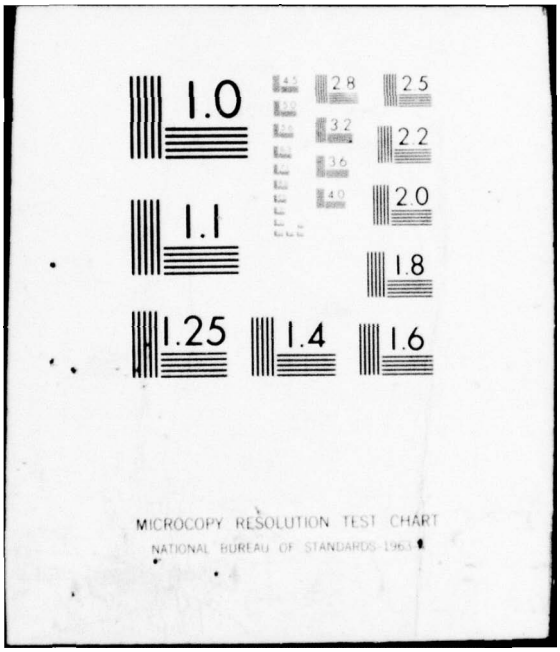
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Test Accessibility Design Guide for Army Mechanical, Hydraulic and Pneumatic Materiel

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BY

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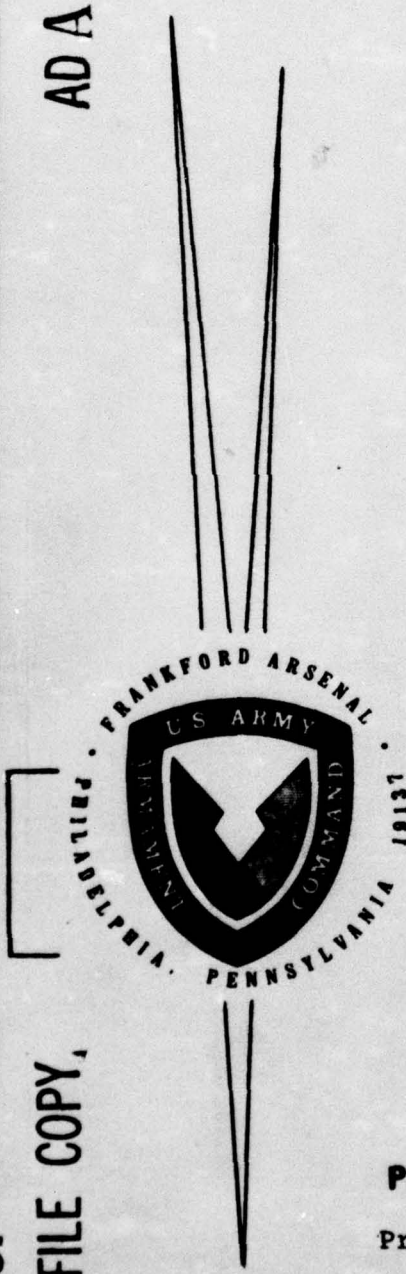

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Test accessibility is becoming more important as automatic test equipment (ATE) proliferates, especially for mechanical, hydraulic and pneumatic materiel. A test accessibility program fits best into the overall acquisition cycle for vehicles or aircraft as a part of the established reliability and maintainability (R&M) methods and procedures. Test accessibility in terms of design considerations for new equipment is a new and most important design goal. It is believed that the most expedient way to "sell" test accessibility is as an expanding part of the standard maintainability program. It is for this reason that the Test

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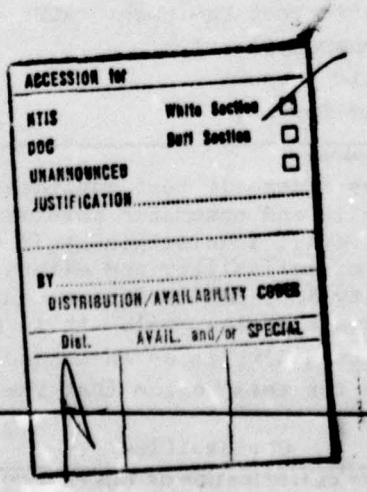
Accessibility Design Guide has taken the approach of interweaving important test accessibility information with maintainability approaches. The design guide has been written for both equipment designers and management; it provides needed data and information to the prime equipment design engineer and to Government/Army/ Industrial procurement and project management personnel.

The Test Accessibility Design Guide for Army Mechanical, Hydraulic and Pneumatic Materiel is written as an engineering design handbook and is a valuable adjunct to the Engineering Design Handbook Series of the Army Materiel Command. It is a maintainability guide covering maintenance planning, test accessibility, test equipment, and related design practices.

The objective of the handbook is to influence design so that equipment can be (1) serviced and repaired efficiently and effectively, (2) tested efficiently and effectively, including malfunction prognosis and diagnosis, or (3) operable for the period of intended life without failures and with minimum servicing. The designer who considers the technology of maintainability and test accessibility as one of the prime design considerations can play a vital part in the solution of the maintenance problem, whereas the designer who fails to do this adds to the intensity of the problem.

The handbook embraces information on the extent and nature of the maintenance problem as it exists today and the principles and techniques that, if included in future designs, will reduce this problem. Part one describes the extent of the maintenance problem in terms of the expenditures of money, men, and materiel. Advanced maintenance concepts using automatic test equipment (ATE) philosophy are provided. Part two presents maintainability and test accessibility objectives, principles and procedures. Part three describes the nature of the Maintenance Problem in terms of the conditions under which weapon systems must be operated and maintained from the logistical, human, and the environmental points of view. Part four deals with design considerations that have general applicability to all types of Army materiel, but specifically oriented to mechanical, hydraulic, and pneumatic materiel. Design considerations applicable to specific types of Army materiel are presented in part five. Automatic test equipment, semi-automatic test equipment and test instruments are described in survey form in part six. A glossary of maintainability terms, technical design terms, and acronyms are included at the end of the handbook.



SUMMARY

Rarely is the design of Army materiel significantly affected by characteristics of the intended test, measurement and diagnostic equipment (TMDE). Rather, problems of testability and test access are cause for testing and test equipment inefficiencies, additional test adapters and dependence upon technician or repairman ingenuity and judgement. This situation has contributed to the proliferation of test equipment in support of all categories of Army materiel.

One aspect of compatibility between the TMDE and the supported Army materiel is test accessibility. Test accessibility means provision within the prime equipment design for improved test efficiency in assessment of equipment condition (good, degraded, or failed) and diagnosis/prognosis of failures or malfunctions.

Test accessibility can be achieved only as an integral part of the prime system design process, accomplished by anticipating the testing environment of the prime equipment and incorporating within the design such items as test points, inspection and interconnection accessibility, and test fittings. As the responsibility for an efficient interface between the test facility and the prime system materiel is shifted more toward the prime system, gains can be expected in achieving the goals of reduced maintenance burden at forward areas, improved materiel readiness and reduced proliferation of test equipment.

The Test Accessibility Design Guide for Army Mechanical, Hydraulic and Pneumatic Materiel has material and guidelines applicable not only to the prime equipment designer but to program managers, maintainability engineers, maintenance planners, and other Government and contractor personnel. However, it is the obligation of the prime equipment designer to apply the handbook guidelines to:

(1) Make accessible for test those points which allow evaluation of the function designated or selected.

(2) Recognize the test equipment to be used for support and its capabilities.

(3) Provide the information from the access points in a form which is most compatible with the assigned test equipments.

Some chapters of this guide are more pertinent to personnel of a given function than other chapters are. Although the entire design guide is recommended reading, brief summaries of each chapter are given to provide insight into the total handbook's content and to direct individuals to subjects of interest. The chapter summaries follow:

- Chapter 1. • THE MAINTENANCE PROBLEM
  The basic reasons why test accessibility and maintainability are so important to the equipment/weapon development process are covered in Chapter 1. Both terms are defined and explained as a large part of the answer to the "Maintenance Problem". The maintenance problem itself is defined as a lack of equipment reliability, maintainability, test accessibility and design consideration of maintenance induced faults. A brief guideline for maintenance fault reduction is given along with a description of the design engineers responsibility in addressing the maintenance problem. Finally, a simple explanation of system effectiveness and "design to cost" is provided.

- Chapter 2. • ACCESSIBILITY AND MAINTAINABILITY CONCEPTS
  Maintainability and accessibility objectives, processes, approaches and flows are explained. The reason for automated test equipment (ATE) is explained along with its effect on the test and repair process. Maintenance concepts are offered along with an explanation of the maintenance levels in both ground and aviation Army units. The importance of contract specification for maintainability and test accessibility is explained including a listing of common MIL Standards and MIL Handbooks. The designers responsibility for maintainability is also detailed with several brief rules to insure that test accessibility provisions are included in equipment design.

- Chapter 3. • APPLICATION AND SELECTION OF AUTOMATED TEST EQUIPMENT IN HYDRAULIC, MECHANICAL AND PNEUMATIC EQUIPMENT TESTING
  Chapter 3 is composed of three sections, I - Automatic Test Equipment, II - ATE Selection, and III - ATE Applications. The first section discusses different types of ATE, ATE test programs and their combined impact on equipment design. The additional design goals required when ATE is to be utilized are briefly discussed. Section II describes how ATE selection should be an integral part of the equipment design and development process. A detailed ATE selection program is described including the effect of the maintenance concept, ATE alternatives, test requirements analysis, support equipment costs, and technical evaluation factors. Section III describes two

example applications, an ATE for Jet Engine Accessories and an ATE for common Army Ground vehicles.

- Chapter 4. • MAINTAINABILITY AND TEST ACCESSIBILITY PROGRAM PLANNING
  Maintainability objectives and maintenance support planning are briefly discussed. Test accessibility is discussed in terms of the responsibilities of the procurement agency and contractor. The responsibilities are identified by proposal and equipment development phases. Integrated logistic support considerations are also identified. The value of ATE compatibility assurance is explained indicating that complex developments may require a compatibility program. Test point selection and test requirements analyses are explained as an important part of the ATE test program design process. The test program design process itself is described in detail as it is a major consideration when ATE is specified in an equipment development program.

- Chapter 5. • REVIEWS AND TRADE-OFFS
  This chapter briefly explains the Army acquisition process with related document definitions as an introduction to an explanation of the reviews required. In process reviews and design reviews are covered. Several checklists are provided to foster proper preparation for these reviews. Responsibilities are defined and the needed documentation explained. Various system trade-off analyses are described including system availability, component availability, maintenance testing, test equipment selection, maintainability considerations, and value trade-off considerations. Several methods of trading-off or comparing alternatives are discussed. Finally, needed design evaluation and equipment specification data are explained for the case where ATE test programs are utilized.

- Chapter 6. • TECHNICAL MANUAL CONSIDERATIONS
  The basic elements of information transfer are described along with an explanation of how these elements affect the generation of technical manuals. Technical manual preparation is discussed as being highly contingent upon the selection of the appropriate maintenance concept and trouble-shooting concept. Diagrams are used to illustrate the timing and activities involved in the generation of technical manuals.

- Chapter 7. • LOGISTIC SUPPORT
  Logistic objectives for the Army are explained in terms of mobility and transportability. The Army materiel life cycle is explained by phase to illustrate the complexity of the

acquisition process. Design-to-cost goals are identified and their effect on life cycle costs by phase is noted. The Army Maintenance Management System (TAMMS) is briefly discussed including the objectives of its more important record keeping functions. Sample data collection is also explained as a simplified approach to TAMMS operation. The integrated logistic support process is explained in detail including implementation, logistic support analysis (LSA), typical LSA forms, maintenance planning, support equipment, the engineering interface, and maintainability factors. Modeling aids used as a tool in LSA are discussed; the modeling process is explained with reference to analytical models and simulation models.

- Chapter 8. • PERSONNEL SKILLS AND HUMAN FACTORS
  Army maintenance skills including the typical maintenance technician are briefly described. Categories of maintenance and maintenance levels in the Army are identified. Human factors engineering is discussed with explanations of human body measurements, and human sensory capacities including sight, touch, noise, vibration, and motion. The ATE-operator interface is also discussed including the operators capability of communicating with the ATE, interpreting and reducing data, and performing diagnostic and repair procedures.

- Chapter 9. • ENVIRONMENT AND OPERATIONAL CONDITIONS
  The severity of environment is discussed to alert equipment designers to allow for climactic effects. Tropical climates, desert regions and arctic regions are referred to. Their requirements of fungus protection, corrosion resistance, moisture protection and environmental equipment testing are noted. A list of materials with associated military environmental specifications is provided. Typical equipment failures resulting from the various environment extremes are also identified. The importance of clean hydraulic fluid is emphasized. Hydraulic fluid corrosiveness and the importance of compatibility with metals and other materials is noted.

- Chapter 10. • THE IMPORTANCE OF PHYSICAL ACCESSIBILITY
  This chapter discusses physical accessibility which is defined as a measure of the relative ease of admission to the various areas of an equipment. Factors effecting accessibility are listed and explained. Checklists are given which aid in establishing appropriate access for mechanical inspection, repair, testing and serviceability. Guidelines for component test accessibility instrumentation are also noted. The value

of mockups for preliminary accessibility checks is mentioned.

- Chapter 11. • DESIGN TECHNIQUES FOR ATE COMPATIBILITY
  Chapter 11 is divided into three sections: I - Identification, Standards and Interchangeability, II - Equipment Degradation, and III - Modularity, Simplification and Functional Partitioning. Section I explains why test points are needed, the ways of specifying an ATE interface and how test point selection can make the use of ATE more worthwhile. Interface compatibility with ATE is a most important consideration and is thoroughly discussed. The following kinds of interfaces are addressed: fluid fittings, temperature measurement, and electrical connections. The subjects of electrical interference, isolation and protection are also discussed along with typical measurement applications in automotive circuits. Interfacing with fluidic control systems and mechanical systems using transducers is explained and an ATE test point guideline list is provided. Finally, the desirability of a standardized ATE interface is noted. Section II addresses overhauls, scheduled inspections, and equipment degradation due to imbedded devices. Section III discusses design partitioning of equipment including the considerations of modularity, packaging by function, physical size, interface design, repairable assemblies, failure mode analysis, and test accessibility. Chapter 11 closes with two checklists to evaluate an equipment design, one for ATE compatibility and the other for maintainability.

- Chapter 12. • MEASUREMENT PRACTICES
  This chapter describes the various techniques involved in the measurement of pressure, temperature, acceleration and flow rate by ATE. Pressure-to-electrical transducers, strain gauge transducers, turbine flowmeters, conical orifices, quarter-circle orifices, platinum resistance temperature devices, thermocouples, thermistors, and accelerometers are all explained including device theory of operation and suitable measurement operation/application. Particulate contamination and measurement in hydraulic systems is also discussed. An example particulate monitoring system is described.

- Chapter 13. • SAFETY
  Personnel safety is important in any equipment design and its aspects are discussed in Chapter 13. A System Safety Program is functionally described and the analytical methodologies of Fault Tree Analysis and Failure Modes and Effects Analysis noted. In addition, the common hazards associated with equipment are mentioned with suggestions for adequate safeguards.

The hazards noted include mechanical, fire, toxic fumes, instability, poisoning, explosion, sprays and fluid handling. Safety guidelines useful in the design of hydraulic/pneumatic equipment are provided. Good design practices are interwoven in the guidelines covering over-pressure, over-temperature, and other design considerations.

- Chapter 14. • GASOLINE AND DIESEL INTERNAL COMBUSTION ENGINES
  Gasoline and diesel engine testing with ATE and BITE is an important development area today. Chapter 14 introduces this topic with a systems explanation of the requirements for engine operational readiness. This is followed by material discussing the requirements and how they may be met with modern testing techniques. Topics explained are performance and fault isolation tests for spark ignition testing, charging system analysis and tests, ignition system testing, and starting system testing. Diesel engine testing considerations are also explained. Finally, a list of candidate engine test points is presented to aid engine test designers.

- Chapter 15. • GROUND HYDRAULIC VEHICLE SYSTEMS
  Testing of hydraulic systems in ground vehicles is discussed in Chapter 15. The use of an external hydraulic source in testing is explained. An example system, the servo controlled hydraulic transmission is used to explain the transducers and interconnections required in an ATE application. Typical hydraulic equipment malfunctions for the Army vehicles are listed along with suggested measurements or test points needed to diagnose those failures.

- Chapter 16. • AIRBORNE HYDRAULIC SYSTEMS
  Airborne hydraulic systems in the Army are prevalent in helicopter applications. Chapter 16 covers the automatic test and monitoring of airborne hydraulics for helicopter systems and in particular, a flight control hydraulic system. Measurements and sensors required in this application are explained. Common malfunctions for helicopter hydraulic controls are also listed with suggested test points and measurements.

- Chapter 17. • GAS TURBINE ENGINES
  This chapter presents a generalized approach to gas turbine monitoring and testing. Malfunctions which are detectable are listed along with the advantages of engine monitoring. System implementation of a test system is briefly explained including internal inspection provisions, modular construction, and environmental considerations. The topics of gas

path analysis and hot section deterioration are also discussed. Various test and monitoring techniques are noted. Finally, four examples of engine test instrumentation are given to indicate the potential parameters which are available for monitoring.

- Chapter 18. • PNEUMATIC SYSTEMS
  Pneumatic equipment is categorized as consisting of four types identified as industrial controls, low pressure pneumatic systems, high-pressure pneumatic servos, and high pressure vehicle systems. Chapter 18 primarily indicates how testing may be accomplished on three pneumatic systems. The three systems are a five-ton truck pneumatic subsystem, an airborne compressor-charged system, and a vapor cycle refrigeration system. Operational principles are explained and typical test instrumentation is discussed. In addition, the chapter contains a malfunction list with suggested diagnostic measurements for an air compressor.

- Chapter 19. • DRIVE TRAINS
  As an example of a complex drive train component, a hydro-mechanical automatic transmission is described. Maintenance, and trouble-shooting including diagnostic measurements on this transmission is explained. Pressure taps and temperature probes are suggested for the automating of test/monitoring of the transmission. A list of candidate test points for drive trains including mechanical shafting, bearings and transmissions is provided for helicopters, two automotive transmissions and an amphibious transmission.

- Chapter 20. • SURVEY OF MANUAL TEST SYSTEMS
  Manual test systems are defined as test equipment, instruments and test stands which measure two or more parameters. Chapter 20 surveys the field of commercial and military test equipment including test stands, mobile test machines, oil analysis equipment, portable hydraulic system testers, leak testers and monitors, dynamometers, torque and speed testers, engine analyzers, ignition analyzers, infrared analyzers, vibration measuring systems and others. The survey data consists of manufacturer information, system description, and a system photograph. Seventy-one systems are presented.

- Chapter 21. • SURVEY OF AUTOMATIC TEST SYSTEMS
  Automatic test systems although few in number today, will be more common in the future. Automatic test and monitoring systems are defined as systems which are computer or controller/

processor controlled. Survey information is provided for fourteen automatic test systems in the same format used in Chapter 20.

PREFACE

Test accessibility is becoming more important as automatic test equipment (ATE) proliferates especially for mechanical, hydraulic and pneumatic material. A test accessibility program fits best into the overall acquisition cycle for vehicles or aircraft as a part of the established reliability and maintainability (R&M) methods and procedures. Test accessibility in terms of design considerations for new equipment is a new and most important design goal. It is believed that the most expedient way to "sell" test accessibility is as an expanding part of the standard maintainability program. It is for this reason that the Test Accessibility Design Guide has taken the approach of interweaving important test accessibility information with maintainability approaches. The design guide has been written for both equipment designers and management; it provides needed data and information to the prime equipment design engineer and to Government/Army/Industrial procurement and project management personnel.

The Test Accessibility Design Guide for Army Mechanical, Hydraulic and Pneumatic Materiel is written as an engineering design handbook and is a valuable adjunct to the Engineering Design Handbook Series of the Army Materiel Command. Handbooks in that series are reference books of practical information and quantitative facts helpful in the design and development of Army materiel so that it will meet the tactical and the technical needs of the Armed Forces. Information on the AMC Engineering Handbook Series can be obtained directly from the Publications and Reproduction Agency, Letterkenny Army Depot, Chambersburg, Pennsylvania 17201. Unclassified documents from this series are available to contractors and universities from National Technical Information Service (NTIS), Department of Commerce, Springfield, Virginia 22151.

The highly technical nature of modern Army materiel and the nature of the service required of it, together with imposed or inherent limitations in design choices, have greatly intensified the problem of maintenance including test accessibility, test design and test equipment. Vital information has been collected from maintenance engineering experience and research. This information has yielded design principles that should be carefully

considered in the design of all Army materiel and systems to assure the maximum practicable simplicity, reliability, maintainability, test accessibility and durability. This action must be pursued with a sense of urgency if the maintenance problem is to be dealt with effectively.

The objective of this handbook is to influence design so that equipment can be (1) serviced and repaired efficiently and effectively, (2) tested efficiently and effectively, including malfunction prognosis and diagnosis, or (3) operable for the period of intended life without failures and with minimum servicing. The designer who considers the technology of maintainability and test accessibility as one of the prime design considerations can play a vital part in the solution of the maintenance problem, whereas the designer who fails to do this adds to the intensity of the problem.

This handbook embraces information on the extent and nature of the maintenance problem as it exists today and the principles and techniques that, if included in future designs, will reduce this problem. Part One describes the extent of the maintenance problem in terms of the expenditure of money, men, and materiel. Advanced maintenance concepts using automatic test equipment (ATE) philosophy are provided. Part Two presents maintainability and test accessibility objectives, principles, and procedures. Part Three describes the nature of the maintenance problem in terms of the conditions under which weapon systems must be operated and maintained, from the logistical, human, and the environmental points of view. Part Four deals with design considerations that have general applicability to all types of Army materiel but specifically oriented to mechanical hydraulic, and pneumatic materiel. Design considerations applicable to specific types of Army materiel are presented in Part Five. Automatic test equipment, semi-automatic test equipment and test instruments are described in survey form in Part Six. Specific references are listed after chapters or sections. A glossary of maintainability terms, technical design terms, and acronyms are included at the end of the handbook.

The Test Accessibility Design Guide for Army Mechanical, Hydraulic and Pneumatic Materiel was prepared by RCA Corporation, Automated Systems Division under Contract DAA25-75-C-0681 with U. S. Army Frankford Arsenal, Philadelphia, Pennsylvania. The technical monitor for this contract was Mr. Filmore Richter.

In addition to the authors, several contributing engineers and managers were most helpful in completing this document. They

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Comments and suggestions on this handbook are welcome and should be addressed to U. S. Army Frankford Arsenal, ATTN: SARFA-FCF-E, Tacony and Bridge Streets, Philadelphia, Pennsylvania 19137.

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PART I

INTRODUCTION TO TEST ACCESSIBILITY, MAINTAINABILITY, AND AUTOMATIC TEST EQUIPMENT

CHAPTER 1
THE MAINTENANCE PROBLEM

1-1 GENERAL

The importance of maintainability and test accessibility in equipment design cannot be overemphasized. Technological advances in the past 25 years have had a dramatic and far-reaching impact on military activities. Technology has increased the rapidity and range of our communications, and the precision and power of our weapons. Mechanical, hydraulic and pneumatic materiel have become increasingly sophisticated and effective. To realize these potentialities, however, designers must give greater emphasis than ever before to those factors that will ensure that our equipment is reliable and maintainable in the field.

Test accessibility in particular has not been given the emphasis it will require in the future. Accessibility is a measure of the relative ease of admission to the various areas of an equipment. Test accessibility expands this definition to include testability and diagnosis of the equipment. This means design inclusion of test points and transducers which is also viewed as a means to improve test efficiency through the use of automatic test equipment. Test efficiency in this context, concerns reduced time, effort, and equipment to accomplish interconnection and test. It also means that an improved confidence is gained indicating that interconnections are correctly made and that test results are adequate and accurate.

1-2 THE RELIABILITY AND MAINTAINABILITY PROBLEM

Lack of satisfactory reliability and maintainability in military equipment has three serious effects. First, the success of vital military missions is jeopardized and the lives of military and

civilian populations are endangered; for example, excessive downtime of radar could cripple our air defense system. Second, support costs are heavy, imposing a strain on production, supply, and storage. The estimate that the cost of maintenance during the life cycle of a modern weapon, or weapons system, is in the order of 3 to 10 times the original cost of the equipment indicates the magnitude of the upkeep cost. Third, many skilled maintenance men are needed, imposing a heavy logistical burden on the armed services. The shortage, the long training period, and rapid turnover of such men make this a particularly acute problem.

1-2.1 THE TEST ACCESSIBILITY PROBLEM

Test accessibility is part of the maintainability problem. Historically, hardware designers of prime equipments for military users have, on the whole, tended either to ignore or de-emphasize the maintainability or "testability" aspects of their designs, leaving the major portion of this work to the user's maintenance personnel. Test accessibility can be achieved only as an integral part of the prime system design process, accomplished by anticipating the testing environment of the prime equipment and incorporating within the design such items as test points, inspection and interconnection accessibility, and test fittings. As the responsibility for an efficient interface between the test facility and the prime system materiel is shifted more toward the prime system, gains can be expected in achieving the goals of reduced maintenance burden at forward areas, improved materiel readiness, and reduced proliferation of test equipment.

1-2.2 MAINTENANCE-INDUCED FAULTS

Over-inspection and too much preventive maintenance also causes problems. These problems or faults are almost impossible to spot or identify because they are inherently covered up by the maintenance process. However, the problem does exist and has been identified many times. One example where records do exist is helicopter maintenance (Reference 1). Table 1-1 presents the percentage of accidents (total, major, and minor) and of all mishaps (total, major, minor, incident, forced landing, and precautionary landing) attributable to maintenance errors.

TABLE 1-1. RELATIONSHIP OF HELICOPTER ACCIDENTS/INCIDENTS TO MAINTENANCE ERRORS

		PERCENT OF TOTAL ERRORS			
		Accidents FY		All Mishaps FY	
		1970	1971	1970	1971
HELICOPTERS	UH-1	6.24	3.99	12.78	5.97
	OH-58A	0	2.13	4.84	1.56
	OH-6A	7.25	3.77	7.93	4.03
	CH-47	6.45	4.35	13.35	6.22

Source: U.S. Army Agency for Aviation Safety

Those features of an equipment design that offer potential for generating maintenance-induced faults are:

(1) An installation that can be positioned in more than one way.

(2) A design that requires unnecessarily complex procedures to maintain.

(3) Locations of hardware, connectors, and adjustment features in areas that are not readily accessible.

(4) A design that neither features equipment handling aids nor considers transportability needs.

1-2.3 SIGNIFICANCE OF THE PROBLEM

The maintenance problem is significant not only because of the cost in lives and dollars, but also because of the cost in decreased weapon-system effectiveness. A system that is down for repair for an excessive amount of time is only part of the total system, and it must be supplemented by the expensive expedient of a complex of extra units, support systems, and personnel. The U.S. Army cannot afford this cost and is looking to maintainability and test accessibility as one of the means for alleviating this problem.

1-3 REDUCTION OF THE PROBLEM

Designers of Army materiel must incorporate qualities of maintainability and test accessibility based on scientifically

developed criteria. Maintainability, as a science, must provide four fundamental ingredients (Reference 2):

(1) Means for scientifically identifying technical data that will permit the isolation of facts that have a direct and paramount impact on improvement of the combat or operational effectiveness of Army materiel.

(2) A scientific method to measure the qualities of maintainability that are incorporated into each newly developed item or system of Army materiel.

(3) A scientific means for rating and evaluating the indistinct concepts of maintainability.

(4) A scientific method of reviewing existing industrial and Army developments to correct deficiencies of commercial and Army items and equipments.

The minimum requirements necessary to achieve a science of maintainability are:

(1) Maintainability and test accessibility guidelines.

(2) Good maintainability principles.

(3) Specifics, when historical background warrants them.

(4) Simple maintainability measuring methods which will require the least amount and complication of work for the design activities and the contractual review actions.

(5) Controlling methods to insure maintainability is built-in.

(6) Recording methods for future statistical analyses to check effectiveness of the maintainability actions.

(7) Good communication (feedback) between maintainability engineer and design engineer.

1-3.1 DESIGN ENGINEER's RESPONSIBILITY

Major contributions to reducing the maintenance problem should be made at the equipment-design level rather than at the level of maintenance-personnel training. Designers must think maintainability and incorporate their ideas at the design's inception. Teaching technicians to deal with countless contingencies, which could have been avoided by better design, requires prolonged training. Also, obsolescence and changes in successive production models of the same equipment will reduce the effectiveness of ongoing training programs.

In the past, most design engineers did not consider testing a device until after an engineering model or prototype had been built. Then, the physical characteristics of the model or prototype were transferred to production drawings with no additional effort devoted to design for testability, usually due to schedule

and dollar limitations. To insure optimum maintainability, test design must be included as part of the system design, hardware design, and software design and conducted in parallel with the other essential design functions. Maintainability design should receive equal or greater emphasis than reliability design, as most materiel, regardless of reliability, will fail during its service life. If the materiel is not designed as a "throw away" item, then it must be inspected, tested, and repaired after failure.

The three most important related questions that a design manager should ask upon assigning a design task to an engineer are:

- What are the equipment failure modes?
- What are the most probable causes of each failure mode?
- What are the indications of failure and how does one determine the specific cause of each probable failure?

The design cannot be considered complete until satisfactory answers have been provided for each of these questions.

1-3.2 GUIDELINES FOR MAINTENANCE FAULT REDUCTION

Specific design guidelines for reducing maintenance error potential or eliminate or reduce maintenance-induced faults include:

(1) Eliminate the possibility of installing equipment in more than one way. This includes positioning of the equipment in the vehicle/aircraft; attaching electrical, fuel, hydraulic, or pneumatic lines, and making connections to ground support equipment.

(2) Components or assemblies which are interchangeable must be identical both functionally and physically.

(3) Minimize the dependence upon training of personnel, marking of equipment, or maintenance and operating instructions to eliminate or reduce maintenance error.

(4) Locate those provisions for adjustments that are to be made by higher levels of maintenance in such a way that they are exposed only to higher-level maintenance personnel in the normal conduct of their work.

(5) Identify complex maintenance tasks early in design developments in order that design changes that will reduce the complexity and criticality of the task may be effective.

(6) Design for ease of handling and include special handling aids, fixtures, cradles, and dollies where they would aid the accomplishment of maintenance.

(7) Incorporate built-in test features in equipment whenever possible. Built-in test features should minimize the need for individual judgment in determining either the need for replacement

or the status of equipment. Desirable features of highly developed built-in test systems are:

(a) Fault isolation capability of 90 percent or more
(b) Built-in self-test capability
(c) Low false alarm rates (2 percent or less)
(d) Failure indicators that identify the failed replaceable unit
(e) Automatic start-to-finish test capability

(8) Place early emphasis upon the human factors aspects of maintenance work. This includes simplification of maintenance training programs, diagnostic and repair manuals, audio-visual aids, special maintenance tools for the equipment design and a recognition of the cost-effectiveness aspects of the depth to which built-in test features should be included and described.

The major thrust of efforts to reduce maintenance errors most often is directed at the organizational level of maintenance because errors at this level have a direct effect upon equipment safety and availability. The guidelines applied to the design of equipment maintained at the organizational level, however, also should apply to the higher levels. These guides extend to the special equipment supplied to support the new equipment. For example, consideration should be given to the operational interfaces of support equipment to insure that the equipment is connected easily to the equipment being tested and that connectors cannot be joined improperly. Test equipment also should feature utilization of automatic test and fault isolation capability to reduce the dependence upon operator skills and prevent operator error.

1-3.3 AN EXAMPLE OF THE MAINTENANCE PROBLEM

Table 1-2 shows the importance of engineering design to the maintenance of military electronic equipment. Significant advances have been made in understanding the nature of the maintainability problem and in developing analytical tools for quantitative treatment. However, any investigation of maintainability soon uncovers the complexity of the total problem, and it is realized that only continued research will provide a complete solution to this problem. With the recognition of the maintenance impact on present systems and the advancing complexity of new programs, it is imperative that exploration of maintainability to be continued (Reference 3).

TABLE 1-2. RESPONSIBILITY FOR FAILURE IN ELECTRONIC EQUIPMENT (Reference 2)

Cause of Failure	Total Failures (%)
Design	43
(1) Electrical considerations	
(a) Circuit and component deficiencies	(11)
(b) Inadequate component	(10)
(c) Circuit misapplication	(12)
(2) Mechanical considerations	
(a) Design weaknesses, unsuitable materiels	(5)
(b) Unsatisfactory parts	(5)
Operation and Maintenance	30
(1) Abnormal or accidental condition	(12)
(2) Manhandling	(10)
(3) Faulty maintenance	(8)
Manufacturing	20
(1) Faulty workmanship plus inadequate inspection and process control	(18)
(2) Defective raw materials	(2)
Other	7
(1) Worn out or old age	(4)
(2) Cause not determined	(3)

1-4 DESIGNING FOR MAINTAINABILITY

Although design for ease of maintenance has always been a part of effective engineering design, the military must insist on application of the new art of design for maintainability. It has been only in the last few years that systematic and formal attention has been given to this area of technology.

Design for maintainability offers the following advantages:

(1) Within broad limits, maintainability can partially compensate for hard-to-achieve reliability to obtain the required system availability.

(2) Increases in maintainability can be achieved with little added development cost.

(3) Maintainability with test accessiblity, when built into the system during development can reduce operating and support costs.

Today, maintainability concepts are being defined so they can be included in design specifications. Progress is being made in reducing these concepts to quantitative terms amenable to measurement, evaluation, and communication. There is also the general need to correlate the concepts of reliability and maintainability with each other and with their influence on such factors as system operational readiness, availability, and overall system effectiveness.

In the chapters that follow, a broad concept of maintainability will be adopted and terms defined. The first of these definitions are the following:

Maintainability - a built-in characteristic of design and installation which is expressed as the probability that an item will be retained in or restored to a specified condition within a given period of time, when, the maintenance is performed in accordance with prescribed procedures and resources. It is influenced by many factors, some of which are: inherent simplicity, ease of maintenance, environmental compatibility, test accessibility, safety characteristics, self-correcting characteristics, redundancy, standardization, skill level requirements, downtime minimizing, life cycle costing, logistic supportability, and mobility characteristics.

Test Accessibility - a built-in characteristic of equipment design and installation providing the means for connection, excitation, determination of operational condition, and malfunction diagnosis by test equipment. It is influenced by the factors: testability, accessibility, test points/fittings analysis or test requirements analysis (TRA), transducer technology, transducer interconnection with test equipment and prime equipment, automatic monitoring and testing, malfunction diagnosis and prognosis, test efficiency, compatibility with test equipment, and standardization.

Maintainability Engineering - the application of techniques, engineering skills, and effort, organized to insure that the design and development of weapons, systems, and equipment provide adequately for their effective and economical maintenance.

Reliability - the probability that materiel and equipment will perform their intended function for a specified period under stated conditions. It is a fundamental characteristic of materiel and equipment, and of major consequence in military usage.

System Effectiveness - a measure of the degree to which an equipment can be expected achieve a set of specific mission requirements, and which may be expressed as a function of availability and capability.

The relationships, assuming independence of factors, are as follows:

System Effectiveness =
Performance X Reliability X Availability
(How Well?) (How Long?) (How Often?)

If any of the factors on the right side of the equation falls significantly below unity, the effectiveness of the system is seriously impaired. Where one factor falls to zero, system effectiveness becomes zero.

1-5 SYSTEM EFFECTIVENESS

System effectiveness may be defined as a measure of customer satisfaction; i.e., the probability that the system will satisfy mission performance requirements when working within specified design limits, or how well it does its job when working properly. System effectiveness implies net worth or value of a product to its user (Reference 3). The principal ingredients of system effectiveness are shown in Figure 1-1.

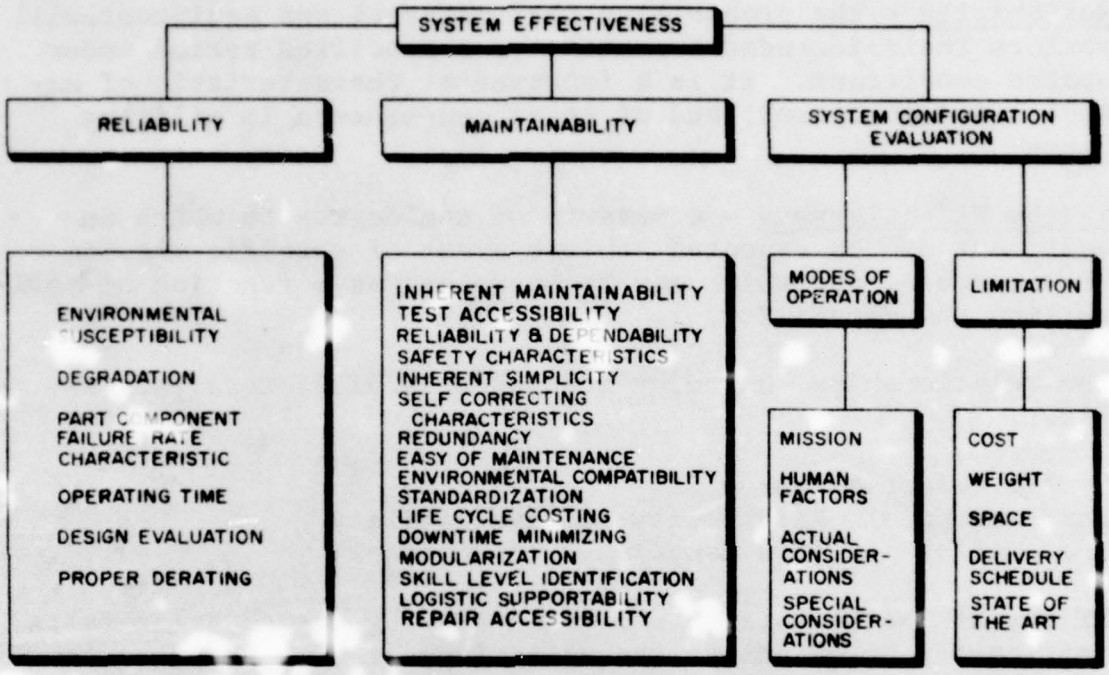

Figure 1-1. Ingredients of System Effectiveness

The effectiveness of many of today's weapon systems is seriously jeopardized by two extreme imbalances:

(1) Increased complexity, new performance requirements, and extreme environments have resulted in higher failure rates, greater requirements for maintenance, and lower availability of the present systems. Product capability often has been compromised by strong emphasis on performance characteristics without the necessary balance of effort toward quantitative treatment and control of the qualities of dependability.

(2) The costs of support for present military systems involve from 3 to 10 times the acquisition cost over a ten-year life span. Much of this high cost is due to lack of recognition and control of reliability, maintainability, and support factors during the successive stages of development, production, and service use. The principal system operational characteristics must be balanced against the elements of total cost. Until recently, very little

organized effort has been applied to quantitative recognition and treatment of maintainability factors during the development and design phases. As a result, the cost of support, the requirements for maintenance time, and the unavailability of equipment are exceedingly high.

1-6 DESIGN TO COST IMPLICATIONS

"Design to cost" (Reference 4) means the management and control of future acquisition, operating and support cost during the design and development process under approved cost objectives. Reliability and maintainability requirements are widely used as a direct approach to the control of support costs and are recognized as primary contributors to operational availability. In Development Concept Papers covering major defense systems, the design to cost goal is normally supported by reliability and maintainability requirements with related thresholds that can be changed only by approval of the Secretary of Defense. A number of current design to cost programs have contractually specified firm minimum reliability and maintainability requirements, while allowing performance to "float". To further control the cost of maintaining several new subsystems, predicted life cycle cost has also been used as a dominant source selection criterion and as a basis for incentive awards.

Although emphasis on reliability is not new, emphasis on field reliability, rather than probabilistically computed subunit, subsystem and system reliability values, is a major new thrust requiring explicit attention for each program. Emphasis on field reliability focuses attention on the formulation and approval of operational demonstration and test program plans to verify that the new system will perform reliably and can be supported under field environmental and operational conditions.

Sufficient time and funds must be available during full-scale development and in limited production efforts for the needed design revisions and corrections to be identified, incorporated and verified prior to large-scale production. Inadequate performance during field tests and the consequent need for design corrections often indicate systems with low inherent reliability, high maintenance costs and a future requirement for retrofit and modification kits.

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3. Maintainability Engineering, Volume 2, RADC-TDR-63-85, Rome Air Development Center, Air Force Systems Command, Griffiss Air Force Base, New York 1963 (DDC No. AD 404 898).

4. Defense Management Journal, Design to Cost Special Issue, Volume 10, No. 4, September 1974.

CHAPTER 2
ACCESSIBILITY AND MAINTAINABILITY CONCEPTS

2-1 GENERAL

The objectives of maintenance (Ref 1,2) are to:

(1) Assist in assuring the capability of Army units to carry on assigned missions.

(2) Predict, prevent, detect, isolate, and correct incipient failures in time by preventive maintenance services and inspections.

(3) Keep all types of equipment ready for their intended use.

(4) Minimize requirements for replacement equipment.

(5) Insure the maximum economical service life of all Army equipment.

(6) Be immediately responsive to, and be prepared to support, increased requirements of support, increased requirements of supported units occasioned by planned increases in operational activity.

(7) Return required unserviceable, economically repairable equipment to a serviceable condition with minimum expenditure of men, money, and material.

(8) Incorporate maintainability design concepts and techniques to achieve the specific maintenance objectives listed in Table 2-1.

To achieve these objectives, the principal factors affecting maintainability must be identified, measured, specified, controlled, and improved as follows:

Identification. The principal factors that limit equipment availability and contribute toward high cost of support must be identified.

Measurement. The principal factors must be expressed in quantitative terms.

Specification. Quantitative requirements must be placed in the procurement specifications along with suitable methods for demonstrating and evaluating conformance of the actual equipment to the requirements.

TABLE 2-1. MAINTENANCE OBJECTIVES

Reduction of:

- Complexity of maintenance tasks.
- Life cycle costs.
- Maintenance skills and training required for maintenance tasks, or elimination of tools and test equipment (special and standard) needed to perform maintenance.
- Mean-time-to-repair to minimum for scheduled and unscheduled maintenance to assure combat and operational availability of the equipment.
- The number and type of repair parts and assemblies needed to support maintenance.
- The number and type of fasteners, and, where feasible, the use of rapid operating fasteners preferably operable without the use of tools.
- Number and type of operating controls.
- Weight in the commodity and package.

Provision for:

- Optimum accessibility of all equipment and components requiring maintenance, inspection, removal or replacement.
- Mobility and handling requirements.
- Self packaging where feasible.
- Military standard components where feasible.
- Maximum storage life.
- Maximum interchangeability.
- Environmental compatibility—climatic, corrosive atmosphere, heat, cold, solar radiation, vibration, snow loads, wind loads, dissimilar metals, fungus resistance, humidity, etc.
- Use of less critical materials.
- Miniaturization, modularization, and unitization, where suitable.
- Pre-production samples.
- Adjustment control locking devices.
- Human engineering aspects for access to maintenance points, such as electrical, pneumatic, hydraulic, lubrication, and fuel servicing.

Provision for: (cont.)

- Bearings and seals which will require the minimum of replacement and servicing during the commodity's life cycle.
- Gears of adequate size and type to satisfy all service overload requirements and which are suitably derated in all aspects for the commodity's life cycle.
- Ease and rapid adjustment in the servicing and replacement of brakes and clutches.
- Removal and installation of instrument panels as units or sub-units with quick disconnects.
- Rapid cleanability.
- Ease of maintenance in the interface of major components.
- Provisions for kits in the basic design, as directed by the procuring agency.
- Maintenance with arctic clothing where appropriate.
- Maintainability source data for preparation of the logistic supportability (technical manuals, provisioning, tasks and skills, etc).
- Preventive maintenance studies.
- Time studies on removal and installation of major items of equipment.
- Test points and test features which stress ease of accessibility.
- Quick disconnect devices for rapid removal and assembly of components.
- Self-diagnostic, automatic, and built-in test and calibration equipment where feasible and practicable.
- Organizational and field maintenance requirements compatible with facilities normally available.
- Derating of electrical, electronic, hydraulic, and structural components.
- Optimum capability to verify performance, anticipate and locate malfunctions, and perform calibration.
- Maximum safety features for both equipment and personnel in the performance of maintenance.
- Technical data to be available for use concurrently with the equipment.

Control. Control must be established, extending from product conception through development, production, and field use. Reasonably accurate prediction is necessary.

Improvement. The end objective is improvement of the quantitative variability and levels of maintainability. Here again, an ability to predict is necessary.

Further consideration of maintainability concepts must reflect and relate to these broad underlying objectives of the maintainability effort. There is great need for prediction methods that can evaluate a design in its early phases and predict the availability and support burden.

Test accessibility is an important maintainability concept which demands the attention of mechanical, hydraulic and pneumatic equipment users and designers. As automatic test equipment applications have increased, it is apparent that the interface with equipments to be tested presents a major problem. Physical inaccessibility and the high cost of modifications to add test points place a practical limitation on applications of automatic testing to most existing Army materiel. In order that future designs would not be similarly handicapped, this design guide and handbook has been written. It presents accessibility and maintainability design concepts and techniques to help alleviate these problems and to help attain the objectives of maintenance.

2-2 THE MAINTENANCE PROCESS

Maintenance is defined as those actions necessary for retaining materiel in, or restoring it to, a serviceable condition. Maintenance includes a determination of condition, servicing, repair, modification, modernization, overhaul, and inspection. Three broad factors which can be used to measure maintainability are design, personnel, and support. Each can be considered as follows:

(1) Design. This encompasses all the design features of the equipment. It covers the physical aspects of the equipment itself: e.g., requirements for test equipment and tools, spare parts, training, and the personnel skill levels required to perform maintenance as dictated by design, packaging, test points, accessibility, and other factors internal to the equipment.

(2) Personnel. This includes the skill level of the maintenance men, their attitudes, experience, and technical proficiency, and other human factors which are usually associated with equipment maintenance.

(3) Support. This area covers logistics and the maintenance organization involved in maintaining a system. A short breakdown of support would include: the tools, test equipment, and spare parts on hand at a particular location; the availability of manuals and technical data associated with the equipment; the particular supply problems which exist at a site; and finally, the general maintenance organization.

2-2.1 THE INGREDIENTS OF MAINTENANCE

Figure 2-1 illustrates the interrelation of design, personnel, and support. The domain of maintenance is shown in the triangular representation. Points lying within indicate the contribution of design, personnel, and support. As an example, the task at point "P" comprises "A" units of design, "B" units of personnel, and "C" units of support. Thus, all real maintenance tasks will contain ascribable quantities of these three factors, and although some of their aspects can be considered to be independent, a certain degree of interdependence may be assumed to exist. For example, design influences support through the requirements for spares; i.e., the use of many nonstandard parts imposes an additional load on the support structure. Similarly,

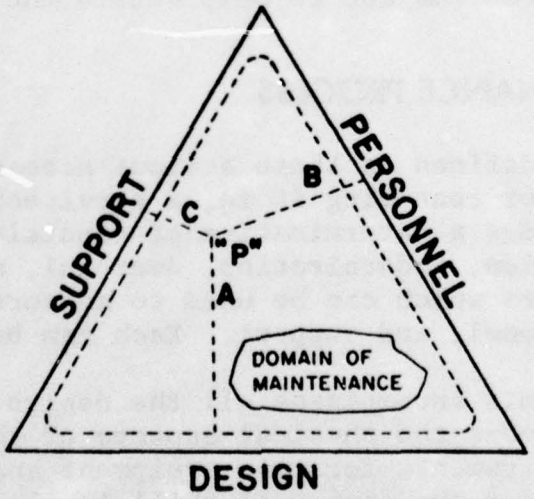


Figure 2-1. Maintainability Factors

the complexity of design will determine the requirements for highly skilled maintenance personnel. The lack of highly skilled maintenance personnel dictates that the design incorporate

features to facilitate maintenance. Personnel will influence technical data requirements, which are a support item. Support will influence, to some degree, both personnel selection and certain design features.

2-2.2 GENERAL MAINTENANCE FLOW

Figure 2-2 is a maintenance flow diagram illustrating the five major sequential steps performed during maintenance. These steps are:

(1) Recognition that a malfunction exists.
(2) Localization of the defect within the system to a particular equipment.
(3) Diagnosis within the equipment of a specific defective part or component.
(4) Repair or replacement of the faulty item.
(5) Check-out and returning of the system to service.

Complementary to these steps are actions associated with assembly, disassembly, cleaning, lubrication, supply, and administrative activity.

Figure 2-2 also illustrates two supplementary paths: one during which obvious malfunctions can be isolated immediately, the other for instances requiring the technician to retrace his steps and perform additional analysis.

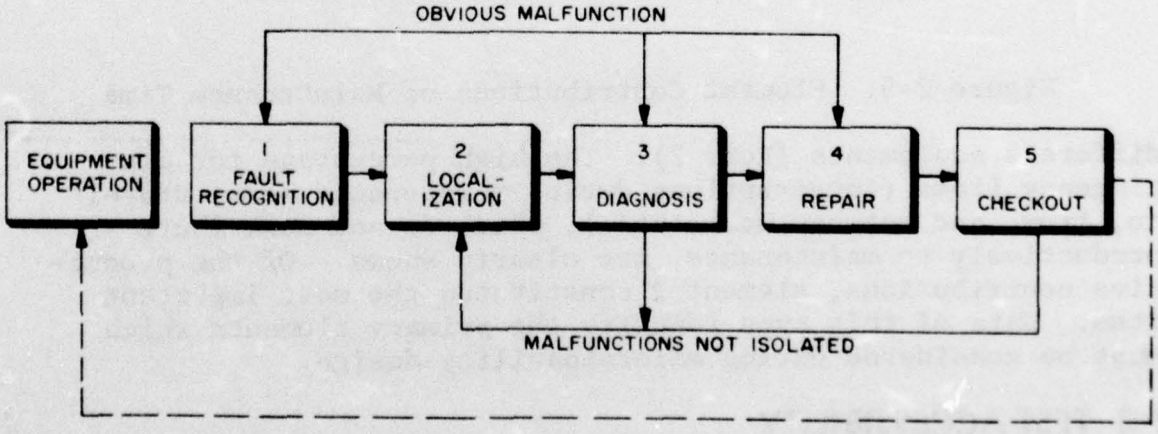


Figure 2-2. Maintenance Flow Diagram

2-2.3 MAINTENANCE WORK EFFORT DISTRIBUTION

The comparative contributions of each time element of maintenance are illustrated in Figure 2-3. The percentages shown have been developed from 101 task measurements taken on three

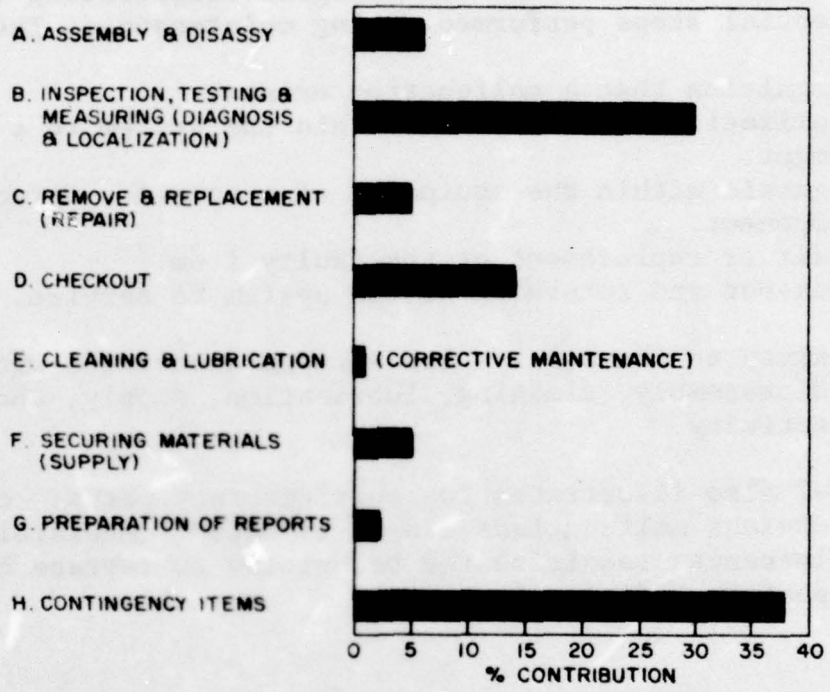


Figure 2-3. Element Contributions of Maintenance Time.

different equipments (Ref. 2). The high percentage for contingency items (interruptions during maintenance work; travel to, from, and between work; etc.), which do not contribute productively to maintenance, are clearly shown. Of the productive contributions, element B constitutes the most important item. Data of this type identify the primary elements which must be considered during maintainability design.

2-3 TEST ACCESSIBILITY

Test accessibility can be achieved only as an integral part of the prime system design process, accomplished by anticipating the testing environment of the prime equipment and incorporating within the design such items as test points, inspection and

interconnection accessibility, and test fittings.

Test accessibility guidelines are needed to provide test measurement or test stimulus points during the design phase of future equipments. At test measurement points, voltage, frequency, pressure, temperature or other test parameters can be sensed by test equipment to aid in evaluating equipment condition. Test stimulus points are means for access which permit external test signals to be applied to the equipment in order to evaluate performance under controlled stimulus. Test point access may be provided by means of transducers, for example, which convert into electrical quantities such non-electrical parameters as temperature, pressure, speed, position, weight, volume, or flow rate. The simplest form of test point access can consist simply of providing mechanical attachment points, pressure disconnect fittings, or identifying rotating shafts to which removable sensors or transducers can be temporarily attached only when testing is underway. Test access to electrical equipments can be provided by terminal points, transmission line taps, or connectors which collect a group of test points.

Test stimulus access for mechanical devices can typically consist of fittings to permit application of compressed air input, or external means for rotating shafts. Electrical test stimuli encompass a wide range of possibilities - dc through microwave frequencies, infra-red, digital patterns, modulated signals, Pulse trains, etc.

2-3.1 PURPOSE OF TEST ACCESSIBILITY

The purpose of providing test accessibility is clearly to facilitate testing. As test points are made more accessible, test equipment setup time is reduced, and the use of test equipment made more convenient. Short setup times are essential to back up the high operating speeds of automatic test equipment, which typically can evaluate performance and diagnose faults within seconds. Disassembly for test access should be avoided because of the risk of failures caused by handling, the possibility of mislaid covers, and the special tools and skills required.

2-3.2 TEST APPROACHES

Test accessibility can be approached from the standpoint of on-line or off-line methods, with manual and automatic sub-sets. Two more dimensions are added to the approach matrix by the

choices of built-in or external test equipment and the level of fault isolation required. A hybrid approach is often necessary to optimize the cost complexity/manning equation. An on-line system may be usable off-line for a different level of testing than would be performed on-line. Where an operator is required, a mixture of manual and automatic approaches could be advantageous. For radios, built-in test circuitry can monitor overall operability, while an external test set may be preferable for locating individual subassembly and component malfunctions. Present gas turbine propulsion systems are usually instrumented to enable the pilot to monitor performance and to identify malfunctions within the limits of the instrumentation and his diagnostic skill. The major purpose of these guidelines, however, is to point the way toward improving test accessibility over current methods, and current implementation is discussed only to provide a starting point.

2-3.2.1 On-Line Test Approaches

Of all test approaches, on-line provides the most rapid response. Since it is always connected to the equipment it is monitoring, it can be designed for continuous monitoring of performance. The advantage to on-line monitoring of an air defense radar are obvious. Although on-line monitoring provisions are usually built-in as a physically integral part of the prime equipment, that is not the only possible implementation. A test set could be plugged into prime equipment at test access connectors and dedicated to that application only. The meters in a radio transmitter and the engine gauges in a jeep are a form of built-in on-line "manual" monitoring of individual test parameters. (eg., signal strength, charging current, etc.) An automatic on-line system would evaluate those (and probably other) parameters as a group and automatically determine level of performance or diagnose malfunctions for display to the operator. On-line testing is the most difficult approach to implement because of the need to avoid interfering with normal operation. However, the on-line approach can be easily implemented on mechanical, hydraulic and pneumatic systems which, in effect, are constantly generating their own test stimuli. The test system needs only to monitor temperatures, pressures, speeds, vibration, etc. and correlate these data. Considerable work has been done, and much remains to be done in analyzing vibration data and extracting parameters of interest from ambient levels and from the influence of adjacent devices and structure. Work is also being done on the use of secondary parameters such as starter motor current plots to obviate the need for cylinder pressure sensors

in internal combustion engine testing.

2-3.2.2 Off-Line Test Approaches

Off-line testing permits the most detailed testing with the fewest design problems, because of the removal of the operational non-interference constraint. The access problem is simplified because equipment can be partially disassembled and probing of internal test points permitted, provided the test area is sufficiently clean.

2-3.2.3 Built-In Test Equipment

Quite frequently it is desirable that some test functions and status or test results indicators be built into the prime equipment. This built-in test capability may vary greatly in complexity depending on the equipment and its use. Perhaps the simplest built-in test capability, although frequently not considered as such, is the ammeter, water temperature gauge, and oil pressure gauge used in automobiles and other equipments containing an internal combustion engine. Another application of built-in test is the performance and diagnostic software used with digital computers. Built-in test applicable to electronic equipment may range from that of a signal strength meter in a radio receiver to a subsystem as sophisticated as that being tested, including use of a digital computer for automatic testing and test results evaluation.

Looking only at capitalization costs, the comparison with an external test set must consider the total cost increase due to addition of BITE versus the total cost of the smaller number of external test sets required for the same purpose. In favor of BITE, regardless of its possibly higher acquisition cost, is the fact that BITE can provide the field user with an on-the-spot indication of performance and required maintenance action, while an external test set may not be available or convenient to use. Without BITE there is always the risk that an equipment will be operated in a degraded condition without the operator being aware of it. The combat pilot would place a high value on the ability to know immediately when deterioration has occurred in his aircrafts' power turbine output torque. Another BITE cost saving is in the reduction of unnecessary equipment removals. Avionics gear, particularly, is prone to hasty removal purely on the basis of suspected malfunction. Spares are then installed while determination of the true cause of the problem is delayed by the original faulty assumption, and operable gear is needlessly pushed into the maintenance pipeline.

Built-in test applications can be expected to increase rapidly as microcircuit technology continues to reduce the size and cost of complex circuitry.

BITE is technically attractive to the designer of small stand-alone equipments, in that the BITE designer does not have to provide an external interface for each test parameter sensor, with the necessarily difficult constraints on signal conditioning and installation required on external test sets. BITE for small engines can cost less and use less space than interface signal conditioners and ATE. However, BITE for small equipment is not without its own technical challenges. Some of them stem from space constraints, the desirability of avoiding overall equipment MTBF degradation in excess of 10 percent due to addition of BITE components, the need for BITE self-test, and the need for special purpose designs for stimulus, measurement, comparison, sequencing and display circuitry. A subtle management advantage to BITE is that it makes the prime equipment designer wholly responsible for test accessibility. Where one manufacturer designs the external test equipment and another designs the prime equipment, it can be difficult to pin down the overall responsibility for test accessibility.

2-4 AUTOMATIC VS. MANUAL TEST EQUIPMENT

For designers who may not be familiar with automatic test equipment, comparison with standard manual test equipment would be helpful. Obviously, automatic test equipment is faster than manual equivalents, but since it is usually more costly, an explanation of the reasons for its growing use is in order.

2-4.1 TEST EQUIPMENT CATEGORIES

Automatic test equipment (ATE) can be of the general purpose or special purpose type. Typically, a special purpose set might generate discrete radio frequencies, while a general purpose ATE would generate a programmable spectrum which included those discretes. However, general does not necessarily mean universal. Economic considerations invariably place bounds on the scope of a general purpose ATE in the form of limitations on such items as stimulus spectrum, number of stimulus generators, and measurement accuracy. Still, because of its wider applicability, general purpose ATE can be expected to have a longer service life than special purpose test equipment, other things being equal. Special purpose sets are less adaptable to changes in prime equipment and are not likely to be useful beyond the service life of the equipment for which they are designed. This

factor must be considered when performing cost trade-offs between general and special purpose ATE. From the narrow viewpoint of initial cost alone, manual test equipment would be favored over automatic, except where response speed and diagnostic complexity made ATE a necessity.

2-4.2 MANPOWER AND SKILL LEVELS

Apart from the problems of set-up and operation, manual test equipment is limited in its effectiveness by the capability of the human operator. The skill and training of the operator determine the accuracy, consistency of results, flow rate, and diagnostic level attainable. The inherently higher speed of ATE, and the sophisticated diagnostic logic which can be programmed into it, reduce manpower levels and skill requirements.

Also, operator fatigue becomes a negligible factor in ATE usage. A cost trade-off manual versus ATE must consider manpower, skill, and training reductions possible with ATE, factors of rapidly increasing importance to the Armed Services. Also to be considered, obviously, are the maintenance manning requirements for the ATE itself, which could favor manual equipment in some applications.

2-4.3 EQUIPMENT AVAILABILITY

Military requirements are growing more sophisticated, and equipment complexity is keeping pace. Add-on hydraulic stabilization systems for tanks have become more complex than entire earlier stabilization systems. Applications of secure communication systems are increasing toward the possibility that all future communications may be secure. Gas turbine engines use fuel controllers which are virtually computers. If the availability of this equipment is to be kept at acceptable levels, maintenance personnel will need the help of ATE.

The availability problem is especially severe on very large weapon systems, where, without ATE, the arithmetic of high parts counts could result in near zero availability despite component MTBF figures upwards of 20,000 hours. The test accessibility problem on such systems is best solved by a built-in ATE.

Although this discussion has centered on the ability of ATE to improve availability by reducing test time, the cost of ATE must be traded against improvements in reliability and maintainability which might also achieve the same availability goal. For small

components, such as fuel controllers, reliability improvements are feasible means for meeting high availability requirements. As complexity increases, ATE or built-in test devices become desirable - and eventually necessary.

2-4.4 SELF-TEST

Ideally, it should be possible to know at all times whether the test equipment is functioning correctly, and an on-line BITE approach is suggested. The difficulties are such, however, that a number of compromises are usually adopted. Operating parameters such as engine timing, other constantly operating clock oscillators, power voltages, cooling air, or interlocks can be continuously sensed, as in an example previously cited for monitored prime equipment. For the remainder of the self-test the operator is involved. With BITE, he could be provided with a test switch to insert a calibrated test reference signal into the circuit. With large automatic test systems, a separate self-test must be conducted, usually from a special self-test program. This program uses internal precision reference oscillators and voltages to check out the measurement subsystem. The stimulus subsystem can then be tested by interconnection to the ATE's own measurement subsystem. Switching commands can be verified as part of the interconnection process. Since this degree of self-test obviously cannot be accomplished while the system is testing other equipment, it is sometimes run before and after usage to verify that there were no failures during operations which followed the first self-test.

2-4.5 TEST LEVEL

The minimal level of test accessibility is required for performance monitoring, - also variously defined as overall, end-to-end, or operability testing. For a power turbine, power output sensing could indicate operability; for an internal combustion engine, manifold pressure and tachometer readings can indicate operability. The sophistication of performance monitoring depends in part on the performance criteria selected. Considerable thought has also gone into helicopter gear box vibration outputs as performance criteria. Since performance monitoring is of major interest at the field or organizational levels, it is preferable that it be accomplished by BITE, rather than by an external test set, which could go astray when needed. Cost considerations could, of course, dictate otherwise.

Where the maintenance policy requires assembly replacement at a particular echelon, test accessibility goes beyond performance

monitoring into the fault isolation (or fault location) category. Fault isolation can reach to the replaceable component level, as it usually must in depot applications where maintenance actions can include component part repair as well as replacement. As fault isolation requirements approach the subassembly and component levels, built in methods become impracticable, in part because the diagnostic logic required soon exceeds the economic limits for special purpose test circuitry. Also, the necessarily extensive interface within the prime equipment jeopardizes performance and reliability. At echelons where disassembly becomes permissible, test points inaccessible at lower maintenance echelons become available for probing and external connection to test equipment which can resolve faults to a finer degree. However, the designer should facilitate test point accessibility even at the depot level, because the increasing use of automatic test equipment in depots demands lower set-up time and minimal disassembly.

2-5 MAINTENANCE CLASSIFICATION

To specify maintainability, it is necessary to determine and define the various types of maintenance activities. Knowledge of the elements constituting a maintenance task will contribute to the ability to relate the affecting factors to maintenance time. The paragraphs which follow describe some of these activities.

Maintenance actions are precipitated by several causes and can occur in different locations. Total maintenance is composed of preventive and corrective maintenance. These have been defined as follows:

Preventive Maintenance. The care and servicing by personnel for the purpose of maintaining equipment and facilities in satisfactory condition by providing for systematic inspection, detection, and correction of incipient failures before they develop into major defects. Adjustments, lubrication, and routine checkout are included in preventive maintenance.

Corrective Maintenance. That maintenance performed on a non-scheduled basis to restore equipment to satisfactory condition by providing correction of a malfunction which has caused degradation of the item to below the specified performance.

These two basic maintenance actions can occur while the equipment is in or out of service. Thus, it is necessary to

recognize not only the type of action, but also the operational status of the equipment. Such considerations are important for the development of figures of merit for equipment maintainability.

2-5.1 DOWNTIME CLASSIFICATION

Figure 2-4 illustrates the relation of the various maintenance activities at the operation level to system downtime. Beginning with the cause of maintenance, either preventive or corrective maintenance is considered. Next, the process notes whether or not an equipment failure is present, and if so, if it is to be considered critical. This information permits the determination of the operational status of the equipment. The final classification made is to assign the resultant maintenance time to one of three categories - no downtime, deferrable downtime, or downtime. From the equipment operational standpoint, maintenance which requires downtime is most important; however, from a resource expenditure point of view, all maintenance requirements are of concern.

2-5.2 TOTAL DOWNTIME PER TASK

The relationship of downtime to other operational considerations are defined and illustrated in Figure 2-5.

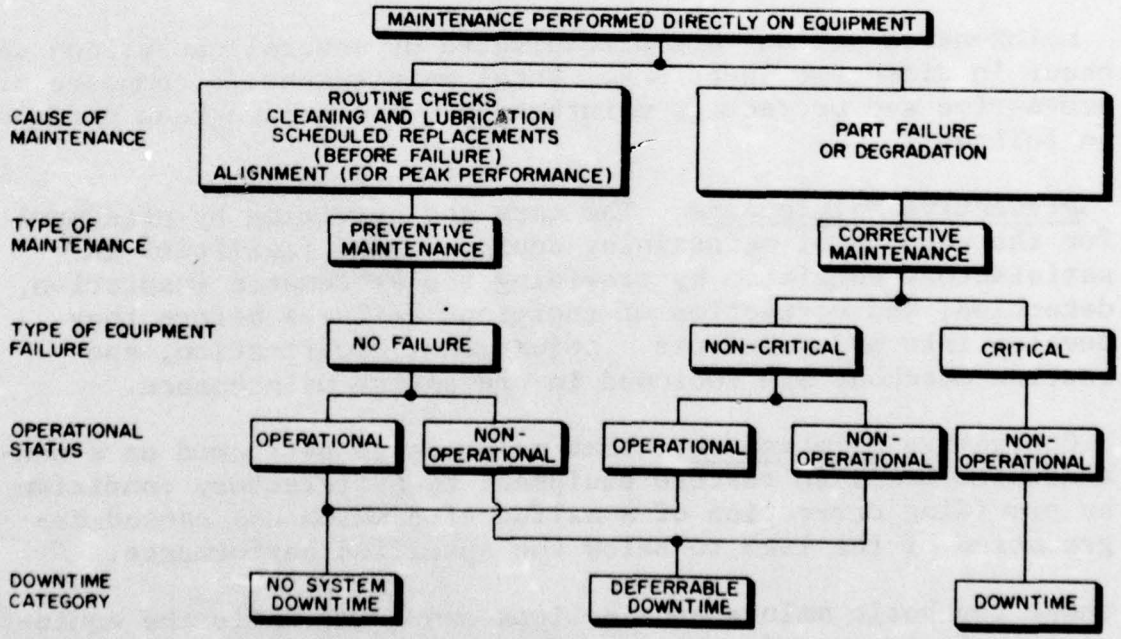
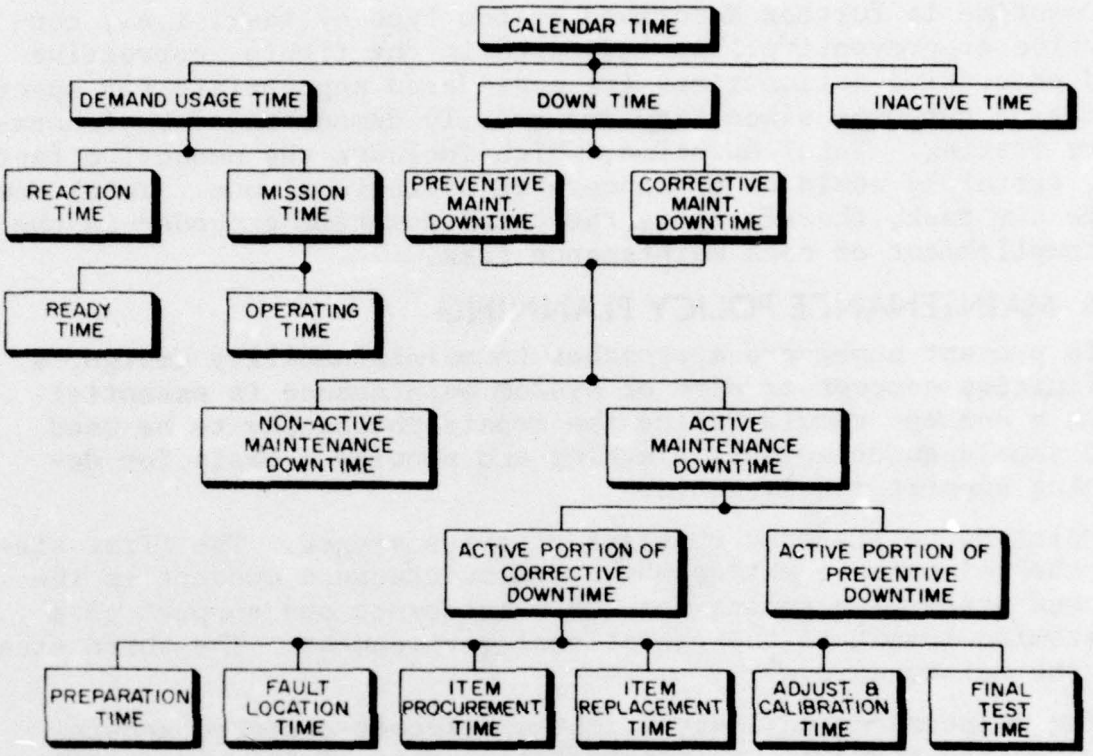


Figure 2-4. Downtime Classification



DEFINITION OF CONCEPTS

Calendar Time. The period of investigation, during which the equipment was scheduled to be in operation for a specified period, and non-operational (or off) during the remaining period.

Total Downtime. That portion of calendar time during which a system is not in condition to perform its intended function: includes active maintenance time (preventive and corrective); supply downtime due to unavailability of needed items; and waiting and administrative time.

Active Maintenance Downtime. That time during which preventive and corrective maintenance work is being done on the system.

Nonactive Maintenance Time. That part of calendar time spent on administrative activities, excessive supply time (such as off-base procurement), and other general areas which preclude operation but cannot be considered productive towards maintenance task accomplishment.

Figure 2-5. Operation Profile

Downtime is further described by the type of task, i.e., corrective or preventive. As indicated in the figure, corrective and preventive action times are considered appropriate for specification purposes since they are readily demonstrated by laboratory testing. Total downtime, which includes the nonactive factor, certainly would be of concern in operational use. Total downtime per task, therefore, is the total downtime expended in the accomplishment of each maintenance task.

2-6 MAINTENANCE POLICY PLANNING

To prevent haphazard approaches to maintainability design, a definitive concept or plan of system maintenance is essential. Such a concept should define the repair philosophy to be used and should guide support planning and provide a basis for defining support requirements.

Maintenance planning consists of three stages. The first stage is the maintenance philosophy. The maintenance concept is the second stage of planning for the maintenance and support of a system/equipment in the operational environment. The third stage is the maintenance plan.

The maintenance philosophy is the customer-directed general maintenance approach and constraints and is limited in detail. The maintenance concept implements the maintenance philosophy, sometimes taking exception to the philosophy, as the level of detail of implementation increases. The maintenance concept evolves through repetitive analysis into a detailed maintenance plan for supporting the operation of the system equipment in the planned operational environment.

The maintenance concept is developed concurrently and iteratively with the operational and design concept to assure the compatibility and cost effectiveness of the system/equipment with the military organization.

2-6.1 THE MAINTENANCE CONCEPT

The maintenance concept is a description of the planned general scheme for maintenance and support of an item in the operational environment. The maintenance concept provides a practical basis for influencing design, layout, and packaging of the system and its test equipment, and establishes the scope of maintenance responsibility for each level of maintenance and the personnel resources required to maintain the system.

Maintenance concepts for the system are established, using prior feasibility studies and maintainability trade-offs between support elements. These concepts provide guidance for the definition of support requirements. Maintenance concepts should include:

- Projected levels and locations of maintenance
- Fault Isolation and system testing approach
- Component repair by maintenance level and location
- Scheduled maintenance requirements and location
- Facilities required at each location
- Support equipment and tools required at each location
- Skill levels, types, and numbers of personnel required at each location
- Supply considerations at each location
- Technical documentation requirements at each location

In selecting a maintenance concept which meets or exceeds the operational requirements at the minimum life cycle cost, the general case is that the operational requirements only influence decisions relative to organizational maintenance insofar as maintenance time is concerned.

Once it is assured that each candidate concept meets the operational requirements (including the maintenance constraints), the candidate should be selected which results in the lowest life cycle cost. It is important to note that the selection of the maintenance concept must be done in conjunction with the selection of the design concept to achieve the optimum results.

The procedures for selecting the maintenance concept for a system are discussed in Chapter 5 (Trade-Offs) and Chapter 7 (Logistic Support). As mentioned previously, the maintenance concept decisions should be made at the same time as the maintainability design decisions.

2-6.2 MAINTENANCE CONCEPT PLANNING

The maintenance concept is the basic document for support planning, and it is imperative that a preliminary approach be developed as soon as the system concept is established.

The description of operational requirements from which quantitative maintainability requirements are derived for the system also provides the logistic support planning criteria on which to base maintenance concepts appropriate to the maintainability requirement. The maintenance concept, which basically defines a criteria governing the scope and proposed methods of repair at each level of maintenance, attempts to satisfy jointly the quantitative maintainability requirement derived for the system, and the planned logistic support environment within which the system is to operate.

The maintenance concept should be developed concurrently and interatively with the derivation of quantitative maintainability requirements for the system. Since the organizational level repair policy to be defined for the system must be compatible with the maintainability indices requirement, the maintenance concept applicable to the organizational level is first established. Maintenance concepts and policies for direct support, general support and depot levels of maintenance are then evolved to support the organizational level concept.

2-6.3 LEVELS OF MAINTENANCE

The present Army maintenance organizations and operations provide testing and maintenance of materiel at five levels or echelons as follows:

- Operator/Crew Maintenance - Effort is limited to preventive maintenance using built-in test equipment (BITE) when provided for system performance evaluation. Maintenance actions consist of visual inspection, cleaning, and minor adjustments that may be performed without the use of tools.
- Organizational Maintenance - Performs more extensive preventive maintenance operations with limited fault diagnosis and corrective maintenance. Clean and repaint materiel. Replace filters, lubricants and tires on aircraft and vehicles. Performs visual inspection of materiel. Fault isolates systems to the replaceable component using BITE and simple separate test equipments. Repairs systems by component replacement and evacuates malfunctioning components to a higher maintenance echelon. Performs some electrical and mechanical adjustments on materiel, primarily those required at the system level.
- Direct Support Maintenance - Performs fault diagnosis, repair, alignment and inspection testing of materiel for return to using organizations. Repairs performed by component, subassembly, and part replacement, as required. Uses BITE, when available, and separate manual and automatic test equipments for fault diagnosis, alignment, and inspection testing. May provide contact support teams to test and repair equipment on site or to assist organizational maintenance activities.
- General Support Maintenance - May operate as either a field maintenance unit or as field depot. Performs fault diagnosis, repair, alignment, and inspection testing of materiel for return to stock. May perform major overhaul of materiel. Uses BITE, when available, and separate manual and automatic

test equipments for fault diagnosis, alignment, and inspection testing. Has machine shop facilities and may fabricate some items in the field. Assists direct support maintenance units when required. Provides direct support maintenance to certain field army and corps headquarters units not supported by assigned or attached direct support organizations.

- Depot Maintenance - Primarily based in the continental United States (CONUS) but may be implemented at the theater army level when required. Performs major overhaul and rebuild of all classes of materiel. Uses separate manual and automatic test equipments, both commercial and military, for fault diagnosis, alignment, and inspection testing. Overhaul and rebuild operations normally scheduled on a production line basis. Has extensive machine shop and fabrication facilities and may, when required, manufacture parts, subassemblies and assemblies.

Army Aircraft Maintenance differs slightly from the above as they are restricted to three levels of maintenance. The three levels of Aircraft Maintenance are:

- Aviation Unit Maintenance (AVUM) - AVUM activities are staffed and equipped to perform high frequency "on-aircraft" maintenance tasks required to realign or return aircraft to a serviceable condition. The maintenance capability of the AVUM is governed by the Maintenance Allocation Chart (MAC) and limited by the amount and complexity of ground support equipment (GSE), facilities required, and number of spaces and critical skills of personnel available. The following tasks are generally performed by Company size units:
  (1) Preventive maintenance, repair, and replacement which sustains a high level of aircraft operational readiness. These tasks include preflight, daily, intermediate, periodic, phased and special inspections as authorized by Maintenance Allocation Charts or higher headquarters.
  (2) Identification of the causes of equipment and system malfunctions using applicable Technical Manual troubleshooting instructions, built-in test equipment (BITE), aircraft instrumentation, test measurement and diagnostic equipment (TMDE).
  (3) Replacement of worn or damaged modules and components which do not require complex adjustments or system alignment.
  (4) Operational and continuity checks including minor repairs to the electrical system.

(5) Hydraulic system inspection and servicing.
(6) Servicing, functional adjusting and minor repair/replacement of the flight control, propulation, power train and fuel systems.
(7) Air frame repair which does not require extensive disassembly, jigging or alignment. The manufacture of air frame parts is limited to those items which can be fabricated with tools and equipment found in current air mobile tool and shop sets.
(8) Evacuation of unserviceable modules/components and end items beyond the repair capability of AVUM to the supporting AVIM.

- Aviation Intermediate Support Maintenance (AVIM) - AVIM activities provide mobile, responsive, "one stop" maintenance support. Maintenance functions which are not conducive to sustaining air mobility are assigned to depot maintenance.

  In addition to authorized AVIM level tasks, AVIM is also authorized to perform all AVUM maintenance functions. Repair of equipment for return to user emphasizes support of operational readiness requirements. Authorized maintenance includes replacement and repair of modules/components and end items which can be accomplished efficiently with available skills, tools, and equipment.

  The following tasks are performed by AVIM units:
  (1) Direct exchange (DX) of components for AVUM units by repairing selected items for return to stock when such repairs cannot be accomplished at the AVUM level.
  (2) Maintenance of (inspect, troubleshoot, test, diagnose, repair, adjust, calibrate and align) aircraft system modules/components.
  (3) Determination of the servicability of specified modules/components removed prior to the expiration of the Time Between Overhaul (TBO) or finite life. Module/component disassembly and repair supports the DX program and normally is limited to tasks requiring cleaning and the replacement of seals, fittings and items of common hardware.
  (4) Repair and fabrication of airframe parts with available tools and test equipment. Unserviceable repairable modules/components and end items which are beyond the capability of AVIM to repair are evacuated to depot maintenance.
  (5) Aircraft weight and balance inspections and other special inspections which exceed AVUM capability.

(6) Quick response maintenance support, including aircraft recovery and air evacuation, on-the-job training, and technical assistance through the use of mobile maintenance contact teams.
(7) Maintenance of authorized operational readiness float aircraft.
(8) Collection and classification services for serviceable/unserviceable materiel.
(9) Operation of a cannibalization activity in accordance with AR-750-50.

- Depot Maintenance
  Depot maintenance of aircraft and aircraft modules/components is managed by the National Inventory Control Point (NICP) in coordination with USAMIDA and USAMC. This level of maintenance is accomplished in organic facilities, by contract with commercial firms, or through interservice agreements with other military services.

  Depot maintenance capability includes the following functions:
  1. Overhaul
  2. Conversions
  3. Major Repairs
  4. Modification
  5. Manufacture of items not supported by the supply system
  6. Complete painting of the aircraft
  7. Analytical, special and non-destructive testing and inspections in support of the NMP requirements for all aircraft, modules and components

2-6.4 SAMPLE MAINTENANCE CONCEPT

The requirements for test access for Army materiel must be based on Army policies, procedures, maintenance levels, and maintenance facility locations.

The trend in military system development and procurement is toward fewer systems that are more costly and more complex. Thus, when a system does fail, it must be fault diagnosed, repaired, and returned to action in much less time than has been allowed for systems in the past. These requirements may appear to be inconsistent in that as systems grow more complex, more susceptible to failures due to higher parts counts, and more difficult to fault diagnose and repair, less time is allowed for the corrective maintenance actions.

This apparent inconsistency can, however, be resolved by proper test access and repair procedure design applied to all levels of the materiel.

A maintenance support concept that will operate within these constraints is summarized below. Where options are shown, they are listed in decreasing order of preference.

(1) Systems are to be tested and repaired where they are installed and operated (aircraft, vehicle, shelter, van, building, etc.). This has advantages of:

- Minimizes costs by minimizing the number of system spares required.
- Minimizes materiel damage due to handling and shipping.
- Minimizes time to return system to action.

(a) System to be tested and repaired by:

- Operator/crew
- Organizational maintenance personnel
- Contract support team from field maintenance unit.

(b) System test equipment:

- None - operating controls and indicators capable of diagnosing malfunctions to the component level
- Built-in test equipment (BITE) and/or diagnostic software
- General-purpose automatic test equipment
- General-purpose manual test equipment.

(c) System fault isolated to faulty component, faulty component replaced.

- Test access shall be external (multipin connector for electronic interfaces, transducer mounting pads for mechanical equipment). Preferably one test connector or group of test connectors for the total system at a readily accessible location. Test access shall not require removal of covers or other assemblies or disconnection of system cabling or piping.
- Components shall be removable/replaceable by one man.
- Components to be prealigned where possible at field maintenance facility, depot or manufacturer.

(2) Component to be fault isolated, repaired, aligned if required, and inspection tested at field maintenance facility.

(a) Test equipment:

- General purpose ATE

(b) Component fault isolated to faulty part. Faulty part replaced. Component aligned if required and inspection tested to insure that repairs are complete and correct.

- Test access shall be on external surface of component (multipin connector for electronic interface, transducer mounting pads or pipe connections for mechanical materiel).
- Adjustment devices shall be clearly marked to identify function and located adjacent to associated test point, preferably on external surface of component.

(3) No special test equipment shall be required or provided. Minimize requirement for special tools at all echelons.

(4) Minimize requirements for special test and/or repair facilities. Where special facilities are required (e.g., screen room, clean room, nitrogen purging, cryogenic cooling, hermetic sealing equipment, etc.), design and spares provisioning should be such that minimum cost maintenance is at the depot level.

(5) Test and repair accessories (e.g., cables, attenuators, test adapters, holding fixtures, etc.) should be supplied as part of a test or maintenance kit. Do not require fabrication in the field.

2-7 MAINTAINABILITY DECISION STRUCTURE

Figure 2-6 shows the interactions between equipment attributes and maintenance actions. The structure can be used for presenting decision choices available to the system designer by providing system and support considerations pertinent to each maintenance action.

2-8 SPECIFICATION FOR MAINTAINABILITY AND ACCESSIBILITY

Maintainability and accessibility must be defined in specific, meaningful, and measurable terms. Whenever possible, specifications should quantitatively indicate desired maintainability as definitely as desired operational performance, e.g., probability of mean-time-to-repair (MTTR) of 30 minutes. There has been a lack of balance in the design and development of new equipment between influence for improved operational performance and influence of improved maintainability. The inability to measure maintainability has been, in part, responsible for this lack of balance.

In the past, maintenance practices depended upon the design engineer to consider ease of maintenance along with numerous other performance objectives. Performance was measurable: maintenance was not. Since the emphasis was on performance, improved performance and generally increased complexity resulted - but not reduced maintenance.

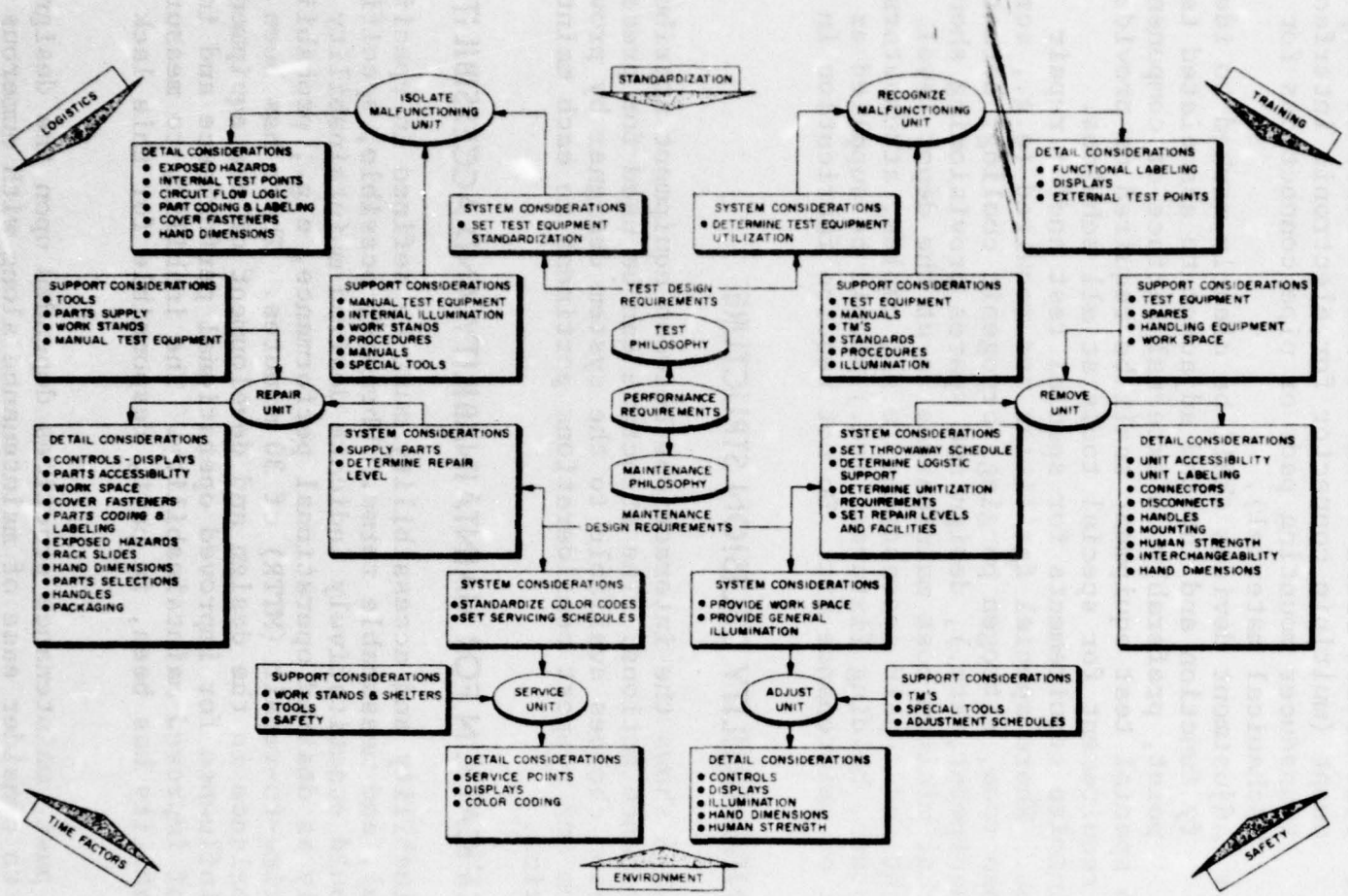


Figure 2-6. Maintainability Decision Structure

Inherent maintainability is created by equipment design which, in turn, is created in accordance with specified requirements. The inclusion of quantitative maintenance requirements as part of the procurement package will form an important foundation on which all subsequent maintainability, maintenance engineering, support philosophies, and logistics must be built.

Current military documents pertaining to the specification of maintainability are listed in Table 2-2.

Additional pertinent Military Specifications and Standards relating to the design and maintenance of Army equipment are discussed in Chapter 11.

TABLE 2-2. MAINTAINABILITY SPECIFICATIONS

Military Specification	Title	Description
MIL-STD-470	Maintainability Program Requirements (For Systems and Equipments)	Covers general requirements for establishing a maintainability program and guidelines for the preparation of a maintainability program plan.
MIL-STD-471	Maintainability Verification/Demonstration/Evaluation	Provides procedures and test methods for verification, demonstration, and evaluation of qualitative and quantitative maintainability requirements. Qualitative assessment of various integrated logistic support factors related to and impacting the achievement of maintainability parameters and item down time is also covered.
MIL-HDBK-472	Maintainability Prediction	Establishes general maintainability design requirements and provides procedures for use in evaluating maintainability of equipment design in terms of quantitative maintainability scores. Utilizes weighting factors for various attributes.
MIL-STD-721	Definitions of effectiveness terms for reliability, maintainability, human factors, and safety.	Provides accepted Department of Defense definitions of terms used in maintainability engineering. Also provides breakout of time-related units in order that a standard understanding of these may be possible.

TABLE 2-2. MAINTAINABILITY SPECIFICATIONS (cont.)

Military Specification	Title	Description
MIL-HDBK-217	Reliability Prediction of Electronic Equipment	Provides a standard reference for failure rate data for certain electronic components and provides derating curves for loading and temperature variances.
MIL-STD-1472	Human Engineering Design Criteria for Military Systems, Equipment and Facilities	Defines general requirements to be followed by development contractor in applying principles of human factors engineering. Provides for consideration of man-machine relation in design of equipment and systems.
MIL-STD-1309	Definitions of terms for Test, Measurement and Diagnostic Equipment (TMDE)	Provides accepted DoD definitions of terms used by TMDE users and designers. Numerous computer engineering terms are included.
MIL-STD-1474	Noise Limits for Army Materiel	Establishes acoustical noise limits for Army materiel and prescribes the associated testing requirements and measurement techniques.

2-9 MAINTAINABILITY INDEX

One of the techniques used to insure maintainability of equipment is a thorough maintainability evaluation during the development cycle of the equipment and prior to its adoption by the Army. Such a technique has been used in the development of maintainability index for equipment and is specified in MIL-HDBK-472. This specification establishes the general maintainability design requirements and provides procedures for use in evaluating the maintainability of equipment design in terms of quantitative scores. The maintainability score is defined in relation to its relative effect in each of five consequence areas: downtime, maintenance time, logistic requirements, equipment damage, and

personnel injury. A sample of the specification, showing the quantitative scoring and evaluation of a typical maintenance design feature, is shown in Table 2-3 as an example of a quantitative approach to the problem.

2-10 DESIGNERS' RESPONSIBILITY

Design engineers engaged in the development of equipment for the Army should be concerned with the following objectives:

(1) Improving reliability to reduce the need for maintenance. Reliability must be designed into items to insure the desired performance for their entire intended life cycles.

(2) Reducing the frequency of preventive (cyclic) maintenance. Reliability improvements will often save time and manpower by reducing the frequency of the preventive-maintenance cycle. This also means more operational time for the component and/or item concerned.

(3) Improving maintainability to reduce downtime. Test and repair procedures must be simplified to reduce the time required to locate and correct faults by providing ease of access and simplification of adjustments and repair.

(4) Reducing the logistical burden. This implies reducing the logistical tonnage required to support equipment in the field, particularly in forward combat areas. Included is the full use of standard parts, components tools, and test equipment. Also included is the interchangeability of parts, components and assemblies.

(5) Reducing the requirements for highly trained specialists. This can be done by simplifying the operation and maintenance of equipment.

(6) Providing for test accessibility. Test accessibility must be designed into the system to insure adequate test system interfacing capability. In spite of the infinite variety of combinations possible in mechanical, hydraulic and pneumatic systems, some basic ground rules may be established. These rules are not peculiar to any system but are consistent with good engineering practice.

Rule 1 - Partitioning of System. Early in the design phase, the system must be partitioned into nearly independent building blocks. To the greatest extent possible, a function should be completed in a single component or assembly. In this manner failures may quickly be isolated to a component. By having each unit nearly independent, the amount of peripheral test equipment required to isolate the failure within the building block will be minimized.

TABLE 2-3. MAINTAINABILITY INDEX FOR TYPICAL MAINTENANCE DESIGN FEATURE

Maintenance Design Feature	Consequence Areas—Weighting Factors				
Internal Accesses	Downtime	Maintenance Time	Logistics Requirements	Equipment Damage	Personnel Injury
1. Place access openings to permit direct access for performing job procedure.	2	3			
2. Provide sufficient access room for all tasks requiring use of one hand.	3	3			
3. Provide sufficient access room for tasks requiring insertion of one hand or both, with tools, cables, etc.	3	3			
4. If technician must see what he is doing, provide sufficient access size to permit sight while hands (and arms) are inserted.	3	3		4	4
5. Make any irregular extensions easy to remove before unit is handled.	1	2			
6. Provide integral rests or supports for units to prevent damage to delicate parts when unit is on bench.	3	3		4	
7. If an adjustment control under an access would be difficult or dangerous to locate, provide a tool guide attached to the access.	1			2	
8. Cover edges of accesses with internal fillets or rubber, fiber, or plastic protection if they might otherwise injure hands or arms.				3	3

Maintainability Evaluation Procedure:

1. For each of the five columns, score the weighting factors for all design features either YES or NO.
2. Score YES for those features adopted and present in every possible application of the equipment.
3. Score NO for those features absent from the design, including those not employed to maximum extent possible.
4. Total each of the five columns and perform the following computation for each column:

$$\text{Maintainability (M)} = \frac{Y}{Y+N} \times 100$$

where

Y = Total of YES weighted factors.
N = Total of NO weighted factors.

5. In order for equipment to be considered as acceptable, it must meet the minimum acceptable score for each consequence area (as set forth in Maintainability Requirement).

Rule 2. The use of redundant elements should be minimized. A redundant element is an element whose failure is not exhibited in the system performance. Redundancy is frequently incorporated to increase system reliability. If redundancy is used, provisions must be incorporated to verify the performance of all redundant elements during system test.

Rule 3. The interface for test of each major building block or component should be standardized. The use of a standard connector will reduce the number of peculiar patch cables required to connect the building blocks to a test facility. Connector coding is required to prevent incorrect insertion of the building block into the test facility. The input and output signals should be allocated to specific interface pins. When the subassembly requires multiple input and output connections, they should also be standardized. Unused power supply connections should not be used for these functions.

Rule 4 - Test Point Allocation. All critical components should have test points available at the interface connector. At critical component interfaces, test points should be provided both at the input source and at the output. The selection of test points must be considered an integral part of equipment design. All test points should be adequately buffered such that shorting to ground or to power supply will not damage the system. In many cases, the same test point may be used as a monitoring point or as a stimuli input. When such a condition exists, proper design of the coupling will greatly facilitate failure analysis and isolation.

Rule 5. The number of adjustments in a system should be minimized. When adjustments are required, the design should allow the adjustment be made at the lowest repair level practical. Critical adjustments must be readily accessible at the system level for final trim.

Maintainability is that part of the maintenance problem which can be designed into an equipment or system and, therefore, is under the control of the designer. Although complex maintenance organizations and supply systems, as well as manpower shortages, contribute significantly to the problem, too frequently, poor equipment design from a maintenance standpoint contributes heavily and compounds the overall maintenance problem. This puts the burden of solving a large part of the maintenance problem on the design engineer. With this in mind, the tenet for design engineers might be: "If we can't design equipment to last forever, let us at least design it so we can keep it going as long as possible, and so we can fix it in a hurry when we need to, with the men available and the tools available".

The designer should first consult the maintenance support plan, described in Chapter 4, and then augment this information by contacting, primarily, the knowledgeable military personnel concerning the capabilities and limitations of operating the maintenance personnel where the equipment will be used, how it will be used, and how it will be supported. In selecting parts for the design, the designer should first consider the use of proven parts with the idea of keeping the use of new and novel components to a minimum. He should be willing to accept what others have done unless appreciable improvements can be demonstrated that do not compromise reliability and ease of repair. However, new design philosophies must not be penalized by being restricted to existing hardware. The final development models should be made simple and reliable, and include those ease-of-maintenance features consistent with the overall design.

The designer should also avoid creating unnecessary maintenance problems by building in maintenance "booby traps". These traps invite errors which are more the responsibility of the designer than they are of the maintenance technician. The ease with which a maintenance task can be performed is directly related to the way in which a system has been put together.

Every designer should attempt to view the maintainability requirements from the standpoint of the maintenance technician. Better still, he should literally put himself in the shoes of the maintenance man by actually performing maintenance and assembly on the hardware he has designed. Designers should remember that their product suffers proportionately to the amount of time it is out of commission, as probably does the maintenance man who has to repair it.

The designer should also bear in mind for future maintenance problems the familiar "Murphy's Law" - <u>If it is possible to do it wrong, someone will surely do it</u>! Unfortunately, the result of doing it wrong too often ends in tragic loss of life and destruction of equipment. The designer could be the real culprit if he deliberately ignores his responsibility of designing his equipment to be easily and effectively maintained. Therefore, in designing equipment, the philosophy of "go right or no go", and "work right or no work" should be used wherever possible.

REFERENCES

1. AR 750-1 Army Materiel Maintenance Concepts and Policies, Headquarters, Department of the Army, May 1972

2. AMCP 706-134, Maintainability Guide for Design, Engineering Design Handbook, Headquarters, U. S. Army Materiel Command, May 1973

CHAPTER 3
APPLICATION AND SELECTION OF AUTOMATIC TEST EQUIPMENT IN HYDRAULIC, MECHANICAL AND PNEUMATIC EQUIPMENT TESTING

SECTION I

AUTOMATIC TEST EQUIPMENT

3-1 GENERAL

The goal of the Army is to use general purpose automatic test equipment (ATE) where possible for both field and depot support of all classes of materiel. Study, development and, in some cases, procurement has been conducted on ATE for mechanical, hydraulic and pneumatic materiel. The Army has at present several types of ATE in use for both field and depot maintenance. These range in complexity and capability from simple tape-controlled checkers to computer-controlled equipments with a wide range of functions. The majority of the ATEs used by the Army at present are not classified as general purpose. Most were designed to support a specific system or class of materiel; hence, stimulus, measurement and control capability are limited.

3-1.1 COMPUTER-CONTROLLED ATE

In this type of ATE, the computer is used only to sequence and control the test, compare measured values with predetermined limits, and to format measured values and results of comparisons for display to the operator. Limited use of the computer's arithmetic and logic capability is implemented in these systems. Arithmetic operations are used to compute ratios or convert measurement parameters, and logic operations are limited to comparisons and branching to subroutines based on results of the comparisons.

Figure 3-1 is a block diagram of a typical computer-controlled ATE. The computer sequences the tests by programming stimulus generators, switches and response converters. The switches connect

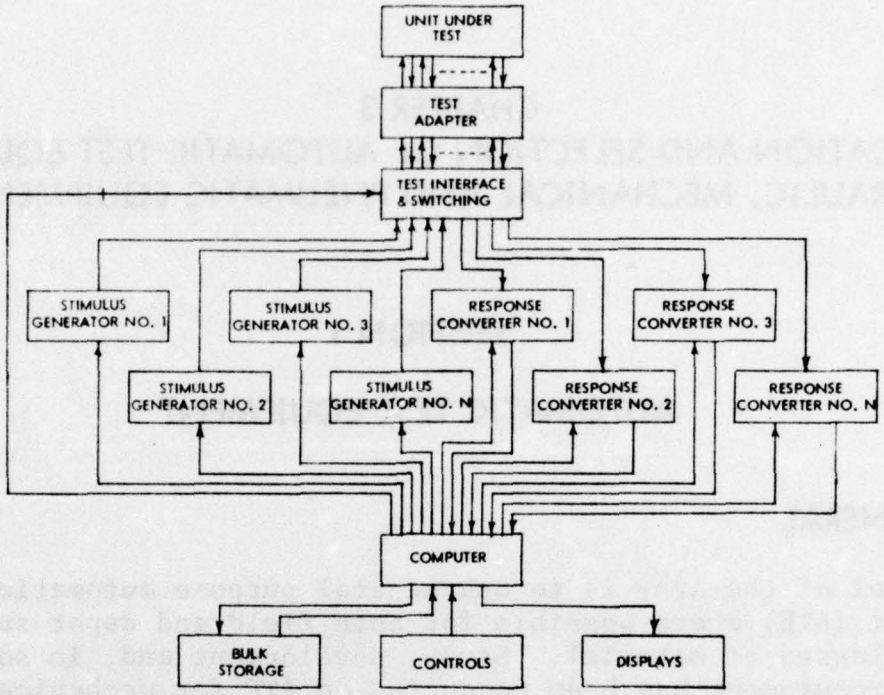


Figure 3-1. Block Diagram of Computer-Controlled ATE

the stimulus generators and response converters to the appropriate test points or other connections on the mechanical, hydraulic or pneumatic unit or system being tested. The bulk storage is used to store test programs and it may be a disc or drum memory, magnetic tape unit or perforated tape and reader. The test program in use is transferred from the bulk storage to the random access memory in the computer. The display may be either a printer or an alphanumeric cathode ray tube (CRT). The minimum controls required are an on-off switch, a test mode selector, a proceed push-button switch and a test address selector. When the test set is capable of manual operation or on-line compilation of test programs, a typewriter keyboard is used for data input and certain control functions.

Individual programmable stimulus generators and response converters are used for each stimulus and response conversion (measurement) function, respectively.

Stimulus generation and response conversion is accomplished with shift registers of the required length and a clock or timing signal generator. When used as a stimulus generator, the computer

loads a digital word into the register. This is applied to the unit or system being tested via the programmable switch. This data is routed to the computer upon command for processing or comparison with a predetermined format or value. The results of the comparison are displayed to the operator and used to determine subsequent test operations.

Analog response converters convert analog signals received from the unit or system under test via the programmable switch to digital data for processing by the computer. Each response converter may contain an analog-to-digital (A/D) converter, or a common A/D converter may be used, with the outputs of the response converters switched to it as required. The response converters may contain amplifiers or attenuators for scaling, filters, mixers, demodulators, counters, power bridges, resistance bridges, impedance bridges, impedance matching devices and/or loads.

3-1.2 COMPUTERIZED ATE USING MATHEMATICAL TECHNIQUES FOR TESTING

In this type of ATE, the computer is not only used as a controller-comparator, but its arithmetic and logic capability is used to generate stimuli and perform measurements. This permits complex measurements to be made, e.g., automatic sampling and evaluation of multi-valued and multi-parameter functions.

Figure 3-2 is a block diagram of an automated test set using mathematical test techniques. The controls, displays, and switching are the same as in the computer-controlled ATE. The bulk storage must be either a disc or drum memory unless a very large random access memory is used in the computer, as rapid access to mathematical routines is required during testing.

For digital testing, the shift register is used as a stimulus generator and response converter in the same manner as in the computer-controlled ATE. In addition, it is also used with the digital-to-analog (D/A) converter for analog stimulus generation.

3-1.3 ATE TEST PROGRAMS

Test programs provide the sequence of GO/NO-GO operations for automatically checking performance and for fault isolation of units, components, or systems to be tested. The prime requirements of a good test program are:

(1) Its ability to determine whether the component or system meets performance specifications.

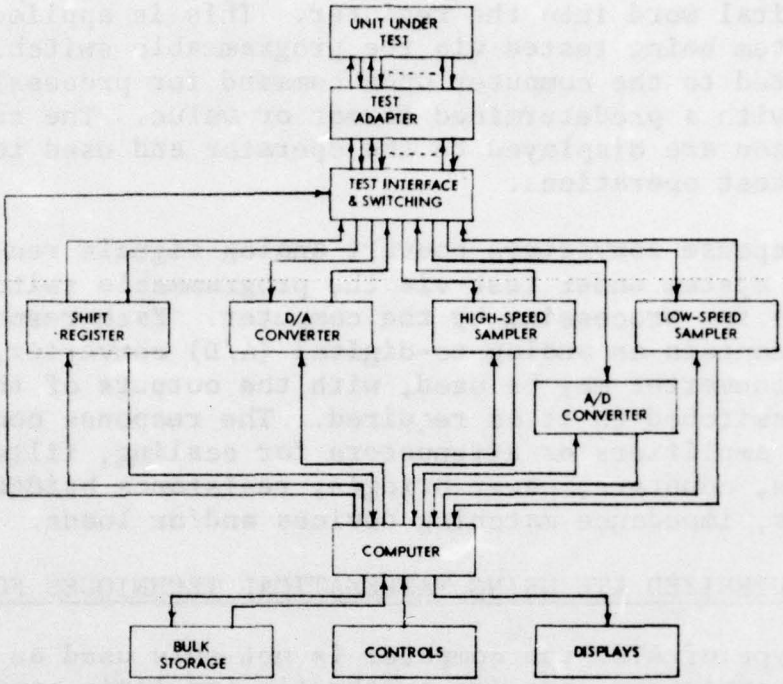


Figure 3-2. Block Diagram of Computerized ATE Using Mathematical Techniques for Testing

(2) Its ability to test operational readiness and to fault isolate the component or system effectively in a minimal period of time.

(3) Minimal effort on the part of the ATE operator to prepare the component or system for test and to run the actual test program.

(4) Minimal effort on the part of the ATE operator or maintenance technician to follow instructions for making adjustments, alignments, or repairs specified by the test program.

The effectiveness of any test program in accomplishing these objectives lies in the ability of the test program designer to fully understand the technology of the ATE system, the component or system to be tested and any engineering subtleties inherent in its design.

A test program is required for each type of unit tested by an ATE. Test cables, and in many cases a test adapter, are required. The test program contains all instructions necessary for the ATE to apply stimuli to the unit or system being tested, measure the responses of the unit to these stimuli, and evaluate the responses. Where adjustments or repairs to the unit being tested are indicated by the evaluation, procedures to perform these actions are

included in the test program and displayed to the ATE operator as necessary. The test program may be recorded on punched cards, perforated tape, magnetic tape, or other temporary storage media for transfer to the ATE bulk storage. The test cables are used to connect the component or system being tested to the ATE and/or the test adapter, if used. The test adapter may contain loads or impedance matching devices and performs special signal conditioning not performed by the ATE. It may contain either or both passive or active devices and, where required, programmable functions under control of the ATE.

After Army maintenance facilities (field and/or depot) are equipped with ATE, it normally is the equipment designer's or manufacturer's responsibility to design the test programs, test cables, and test adapters for his equipment. The test program design is prepared as flow charts and compiler input statements. Coding, compilation, validation, acceptance, and reproduction of the test programs and fabrication of the test cables and test adapters may not be performed by the equipment manufacturer. These test program inspection and production functions usually are performed either at an Army CONUS depot or by the ATE manufacturer, supported by the equipment designer's/manufacturer's representative during test program validation.

Figure 3-3 is a flow diagram of the ATE test program preparation process. The solid blocks indicate the equipment designer/manufacturer's responsibilities. If an equipment is to be supported by ATE, the Army procurement activity will provide the equipment designer/manufacturer with the ATE specification and programming manual. The ATE specification will describe the stimulus and measurement functions, ranges, accuracies, arithmetic and logic capability, and the ATE test interface with the component or system being tested. The programming manual will describe how to prepare the test programs and the descriptors to be used in writing the program. It will also specify the format (drawings, specifications, parts lists, descriptions, etc.) for the test interface design. The test program design will be prepared in flow chart and computer coding sheet format in a high-level language, e.g., ATLAS (Abbreviated Test Language for Avionics Systems), or OPAL (Operational Performance Analysis Language) for input to a test program compiler. The high-level language consists of sufficient VERBS, NOUNS, NOUN-MODIFIERS and syntax rules to completely define the performance of the component or system to be tested and to specify its interface with the ATE.

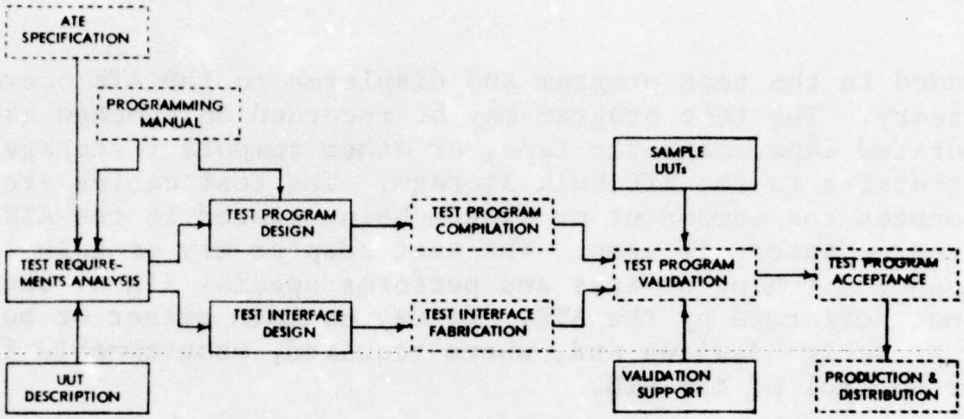


Figure 3-3. Flow Diagram of ATE Test Program Preparation Process

The equipment designer/manufacturer will prepare the description which specifies the component to be tested, its performance, failure modes and the most probable cause of each failure. The test requirements analysis determines the tests and parameter values and limits necessary to verify component performance and to isolate each malfunction. The test program and test interface design data is delivered to the procurement activity for transmission to the test program production facility.

Once the test program is compiled, (processed in a computer to translate it into ATE machine language with the necessary subroutines, test addresses, etc.) and the test interface fabricated, it is ready for validation. This is accomplished by testing sample components on the ATE. The samples are selected to verify component performance and to isolate malfunctions inserted into the components to be tested. The equipment designer/manufacturer is responsible for supplying the sample components and for component and test program design support during validation. This support consists of spare parts for the components, repair of malfunctioning components and the design of any necessary changes in either the test program or the test interface.

After the test program has been validated and accepted, it is reproduced (additional copies made) and distributed to the ATE-using activities. At the same time, the test interface hardware is fabricated and distributed to the ATE-using activities.

3-2 IMPACT OF ATE ON MECHANICAL, HYDRAULIC AND PNEUMATIC DESIGN

Designing mechanical, hydraulic or pneumatic equipment for compatibility with ATE enhances the maintainability of that equipment

and contributes significantly to overall mission success. Increased benefits in maintainability can be obtained with relatively minor effort on the part of the designer, provided certain guidelines are established and executed.

3-2.1 DESIGN GOALS

Greatest impact on the designer is the realization that the support equipment has been built before the equipment to be tested and that design goals must include appropriate consideration of testability. First and foremost, ATE compatibility must be considered as an integral part of the entire design and development effort, from proposal to selloff. This can best be accomplished by clearly defining ATE compatibility requirements as part of the overall program plan and including this definition in all detailed system and equipment specifications. The following design objectives are of major importance.

3-2.1.1 Functional Modularity

Current state-of-the-art components are conducive to modularized packaging. This is particularly true in the case of integrated circuits. For ATE compatibility, modularization alone is not the sole design criterion. Circuits and connectors must be designed and packaged according to function in order to facilitate performance testing, fault isolation and repair.

3-2.1.2 Disposal-on-Failure

Wherever possible, circuits and systems must be packaged into discrete replaceable modules and components of such cost and reliability that disposal-on-failure rather than repair is the most cost-effective logistic support action.

3-2.1.3 Test Points

A sufficient number of test points must be provided at readily accessible connectors to permit non-ambiguous fault isolation.

3-2.1.4 Minimal Reliance on Operator Actions and Skill

In automatic testing, the operator is the slowest element in the loop, and should be used only for selecting a test program and for connecting interface devices and cabling. Manual actions (alignments, adjustments, control settings, etc.) are inefficient and should be avoided if possible. Complete elimination of all

controls and adjustments on components to be tested should be a design goal.

Users of conventional test equipment are skilled technicians, thoroughly familiar with the component or system to be tested, who can be expected to apply judgement and experience in troubleshooting failures. With ATE, however, troubleshooting procedures are embodied in the test program. The operator is usually less familiar with these procedures, as well as with the operation of the component or system to be tested. Therefore, one cannot depend on the ATE operator for correcting procedure errors, for interpreting results, or for fault isolation.

A significant difference between automatic and manual testing is the application of the computational and logical capabilities of the ATE computer. Long, involved calculations or complex, logical sequences which would thoroughly confuse the average technician are now entirely feasible. Troubleshooting is not limited to simple step-by-step signal tracing. More sophisticated diagnostic techniques which use the capabilities of the ATE computer can be applied to achieve more reliable fault isolation with fewer test points.

3-2.1.5 Mechanical Design

For ATE testing, the rules for packaging and for bringing out parameters and test points to surface connectors are somewhat different. For example, the input/output interface must not only provide the normal signal interconnections with other components, but must also facilitate performance testing and fault isolation of the component itself. This could mean more test points, tees, adapter fittings, and associated wiring and connector terminals, more shielding, and larger connectors on both components and systems. The criteria for mechanical design also becomes more stringent in terms of human factors, particularly component accessibility and replacement, equipment handling, and tester hookup and disconnect. Independent test of associated components and component units is required.

SECTION II

AUTOMATIC TEST EQUIPMENT SELECTION

3-3 ALTERNATIVE MAINTENANCE CONCEPTS

Maintenance alternatives will be directed toward optimizing acquisition cost, life cycle cost, manning, skill levels, and equipment availability. Alternatives will be based on defining the spares policy, the level of repair and the repair/discard policies at each maintenance level. Maintenance alternatives are likely to be straightforward and consistent for individual equipments or systems. Where an extensive installation of heterogeneous equipment is being planned, as for an aircraft or vehicle design, maintenance policies can become more complicated. For example, while it may be economically acceptable to discard defective components on one equipment because of relatively low replacement cost, such a policy could be prohibitively expensive on another equipment which uses more costly components. Furthermore, many equipments still in inventory are not modular in construction and if such equipments are to be repaired, it will have to be to the part level, regardless of the level of repair specified for other equipment.

The fact that a system or equipment may already be operational under a previously established support concept does not assure that the same support concept will be satisfactory for a new and different application. Different maintenance concepts are generally employed for depot and field maintenance.

The level of repair and availability requirements will, of all logistic considerations, have the greatest impact on ATE selection. The ATE will have to provide a fault isolation level which is consistent with the specified level of repair. Since the level of repair policy does not necessarily limit the means for accomplishing the required fault isolation level, the ATE evaluator can consider both on-line and off-line options. However, a tight availability requirement could dictate an on-line ATE configuration for achieving the desired level of repair.

The processes of selecting and formulating the logistic support concept can be iterative, as concepts are successively modified

for best match with technical feasibility and cost of the ATE and the prime equipment. The need for iteration is more apt to be evident with BITE than with off-line or external on-line ATE, because of tighter technological, space, and cost restraints.

3-4 RELATIONSHIP TO THE ACQUISITION PROCESS

The timing of ATE decisions is a function of the type of ATE being considered and the point in the acquisition process at which deliberations are in process. Generally, on-line equipment must be selected earlier in the acquisition process than off-line equipment, with BITE being the most critical on-line approach with regard to timing. Since BITE is part of the prime equipment, decisions relative to its use and functions must be made during the Concept Phase. If decisions are deferred until validation, potentially costly design changes may be called for. External on-line test equipment should also be selected during the Concept Phase, although the risk incurred in waiting until Validation will be less than in the case of BITE, and will depend upon the amount of interface equipment which will have to be added integrally to the prime equipment design. The selection of off-line test equipment sometimes is deferred until prime equipment production or beyond. However, it is much more desirable to select the ATE no later than Validation, because the designer can realize in advance the need to configure the prime equipment to facilitate test point accessibility. He can also partition circuitry for easier fault isolation, with significant benefits in testability, test time, and ATE adapter and software costs, if he is made aware of the ATE being contemplated while he is designing the prime equipment.

3-5 THE GENERAL PROCEDURE

3-5.1 INTRODUCTION

The general procedure for evaluating and selecting ATE systems is keyed to the definition of the prime equipment logistic support concept. The logistic support concept matures in parallel with the prime equipment acquisition process, as the maintenance engineering analyses (MEAs) are updated to reflect the increasing level of available detail concerning configuration of the prime equipment. As stated previously, the ATE selection procedures were developed to assist in managing the ATE portion of prime equipment programs, which involves directing and coordinating the work of specialists assigned the details of that task.

3-5.2 SYSTEMS IN DEVELOPMENT

For systems still in development, or contemplated to be in development, entry to the ATE evaluation procedure is at entry point 1 in Figure 3-4 (Reference 2). Details of equipment to be supported would not be firm. However, equipment could be described in terms of the numbers to be deployed, where they will be used, and their function. During preliminary design, reliability

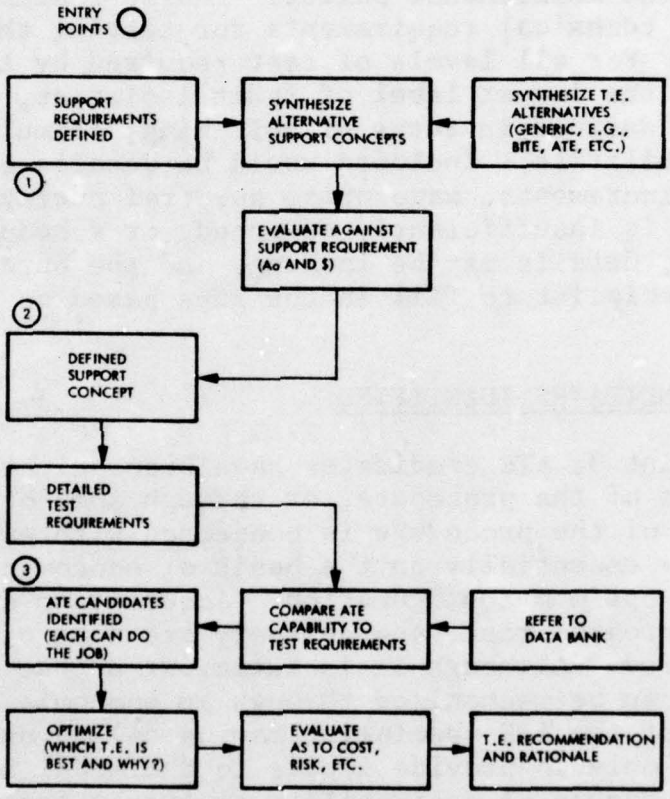


Figure 3-4. Support and Test Equipment Evaluation Procedure

data and equipment configuration in terms of module quantity could be synthesized by similarities to existing equipment. The maintenance workload is a function of MTBF's, MTTR's, requirements for system availability, etc. From these requirements the procedure should provide guidance in synthesizing alternate support concepts such as built-in test, component discard, DS level component repair, etc. The test equipment alternatives would at this point be synthesized and described generically, that is, general purpose ATE, module tester, Go/No-Go BITE, etc. Some alternatives would exist in combinations such as, for example, built-in test for overall operational monitoring, and off-line

testing for module fault isolation. A support concept would be selected from evaluation of alternatives on the basis of operational availability (Ao), hardware and manning costs.

3-5.3 SUPPORT CONCEPT DEFINED

At entry point 2, the support concept has already been defined either as a result of the previous steps, or through other means for defining the maintenance policy. The next step is to define in detail the technical requirements for testing the equipment to be supported. For all levels of test required by the support concept, down to the lowest level of fault isolation, test requirements must be defined in terms of switching, stimulus, and measurement capabilities. Included would be details on accuracies, programmable increments, waveforms, spectral purity, etc. Where design status is insufficiently advanced, or schedule pressures do not permit, details may be lacking, and the burden will fall on the ATE specialist to fill in the gaps based on judgment and experience.

3-5.4 ATE CANDIDATES IDENTIFIED

At entry point 3, ATE candidates have been selected through previous steps of the procedure, or through some other process. The remainder of the procedure is concerned with evaluating the alternatives - essentially on the basis of economic factors - and selecting the optimum configuration. Acquisition cost, manning cost impact, program risk, and delivery are some of the factors to be considered. Although it is anticipated that the optimization process can be mechanized through an economic analysis model, the judgment of the ATE specialist may be called upon in the final selection, if only to provide inputs to the model in the form of risk factors, degree of desirability of excess test capability, etc. The final result is selection of the optimum ATE to meet a maintenance concept, and the rationale to justify the selection to the eventual user of the equipment.

3-6 FROM SUPPORT REQUIREMENTS TO SUPPORT CONCEPT DEFINITION

3-6.1 GENERAL

The first part of the evaluation procedure, the portion between entry points 1 and 2 on Figure 3-4, is expanded and described in this section. This is the only time in the acquisition process where it may be economically feasible to specify built-in or on-line test methods. At this time plans can be made for integral

test devices or for an interface with external test equipment. Later in the acquisition process, the addition of test equipment provisions can become prohibitively costly, because of the need for design changes. The ideal subject for ATE application would be an all new weapon. New aircraft and vehicle designs usually contain a mixture of new and existing subsystems and equipment, which complicates the ATE selection process, pointing toward a mix of manual and automatic testing. Figure 3-5 summarizes the process to be described and suggests the organizational responsibility for each step. Later portions of this section will elaborate, where necessary, on the steps shown in Figure 3-5 and which are briefly discussed below:

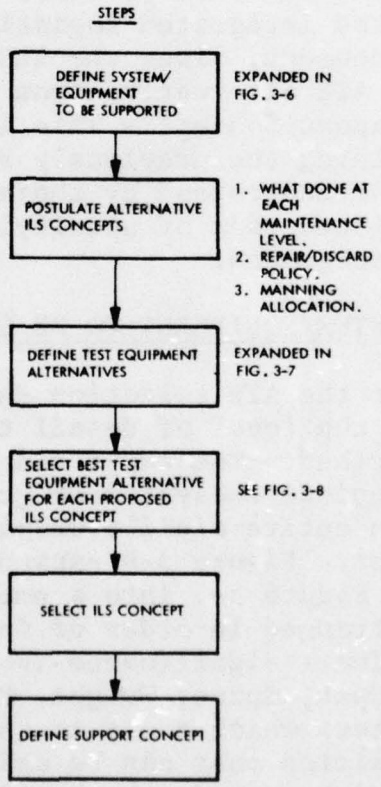


Figure 3-5. Support Concept Definition

(1) Define System/Equipment to be Supported - A basic first step is to define the equipment or system to be supported.

(2) Postulate Alternative Integrated Logistic Support (ILS) - This task consists of identifying ILS concepts for comparative

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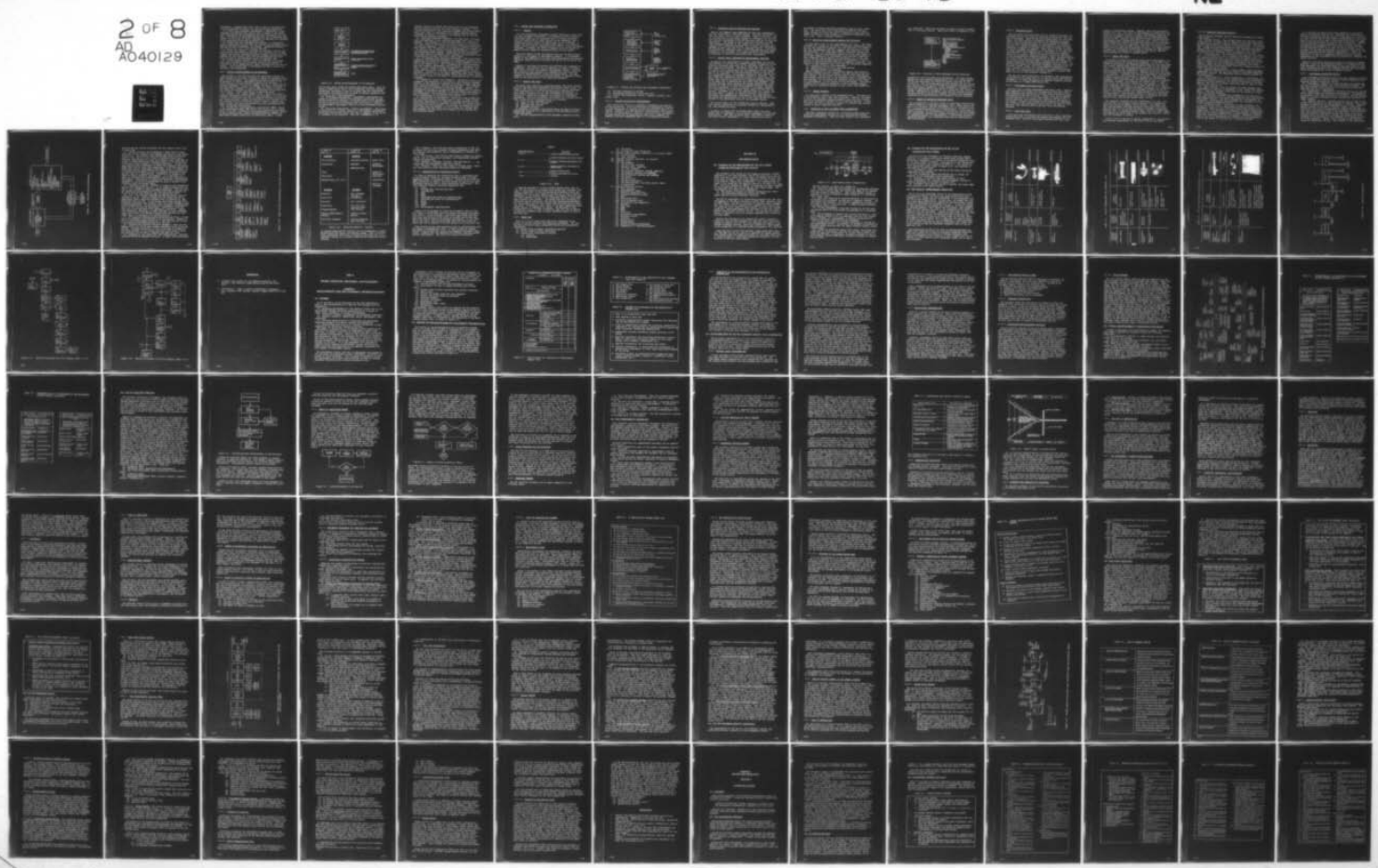

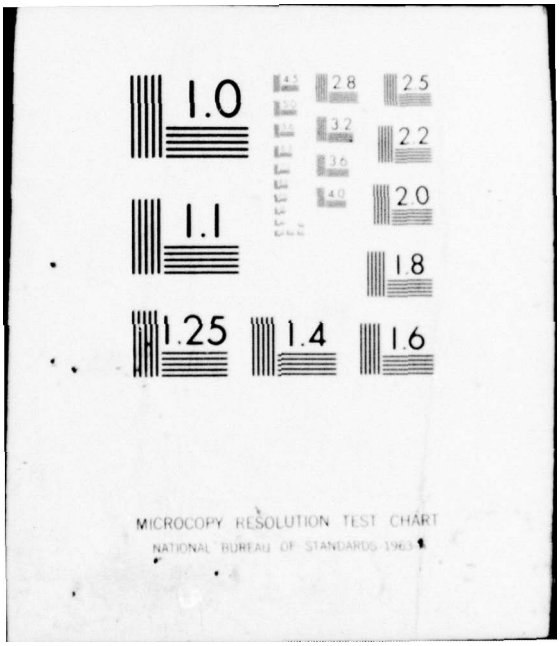
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evaluation. Although this step is not a part of the ATE selection and evaluation process, the two are mutually dependent.

(3) Define Test Equipment Alternatives - Definition of test equipment alternatives may require that a number of test equipment alternatives may be suggested for each alternative ILS concept. The detail to which ATE alternatives can be specified will depend on the level of detail available to describe the equipment to be supported (first step in Figure 3-5).

(4) Select Best Test Equipment Alternative - A cooperative task is envisioned to select the best of the test equipment alternatives for each alternative ILS concept. Selection criteria will include ILS, cost, and technical factors.

(5) Select ILS Concept - Although not strictly a step in the ATE selection and evaluation process, the selection of the maintenance and related integrated logistic support concepts will determine the ATE concept, since the ILS alternatives will each have included an ATE alternative from the previous step.

(6) Define Support Concept - This is essentially the paperwork task of defining the previously selected ILS concept in terms which can be understood by those concerned with the ILS interface. The related task of specifying the ATE is seen as requiring an ATE background.

3-6.2 DEFINE SYSTEM/EQUIPMENT TO BE SUPPORTED

The validity of the ATE selection and evaluation process depends largely on the level of detail to which the supported equipment can be described. The supported equipment could consist of an aircraft or vehicle subsystem or group of subsystems. It could comprise an entire missile weapon system, or simply, an individual equipment. Figure 3-6 expands the single step shown at the beginning of Figure 3-5 into a number of levels of detail. The levels are arranged in order of increasing detail going from top to bottom. Their significance is discussed below:

(1) Budget - Cost, Space, Weight, Power - These are typical budgetary parameters which apply to the equipment to be supported. A bound on acquisition cost can be eased by proving a life cycle cost reduction which exceeds the acquisition cost increase due to the proposed ATE by a sufficient margin to make a credible case. Space, weight, and power constraints are more confining particularly in airborne applications.

(2) Reliability, Maintainability, Availability (RMA) - Early in the development phase, RMA factors will exist only as predictions, if at all. Reliability and maintainability factors should be used conservatively. Mean-time-between-failure (MTBF) and mean-time-to-repair (MTTR) are, by definition, means. Actual

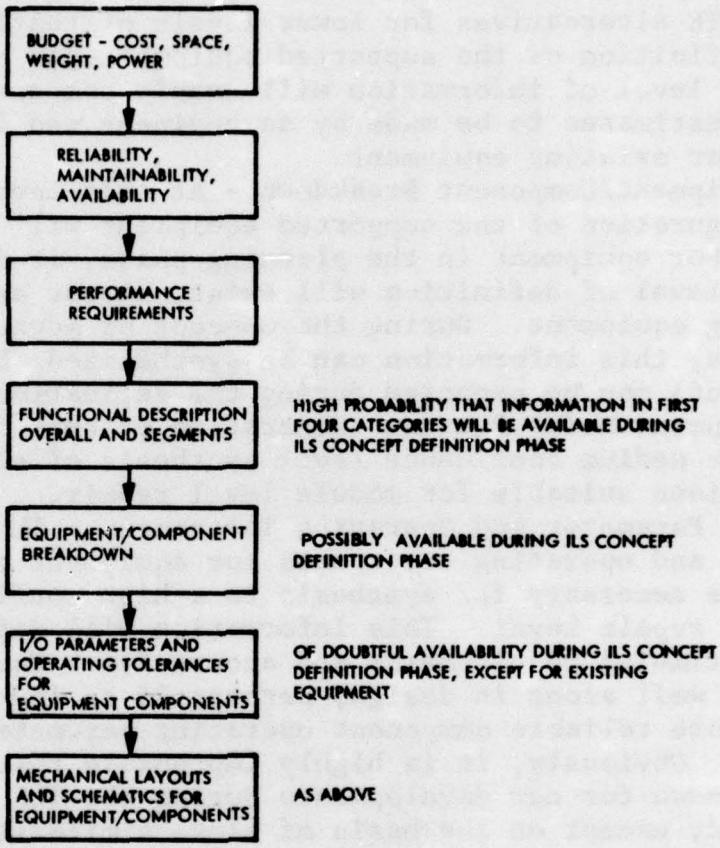


Figure 3-6. Define System/Equipment to be Supported

failure and repair times can deviate from those means. Also, because of human error, skill level variations, and other factors, operational experience is apt to be worse than the predictions. Operational availability will be based on mission scenarios, and is likely to be a firm requirement.

(3) Performance Requirements - Performance requirements are needed to synthesize end-to-end performance monitoring systems, whether built-in or external. An initial idea of the complexity of such a system can be estimated from the accuracy, stimulus, and measurement requirements implicit in the performance specification.

(4) Functional Description - Overall and Segments - This level of definition is a further expansion of performance requirements. Functional descriptions should get down to segments of the system or equipment to be supported. From this information it is

possible further to define BITE devices and to start defining off-line ATE alternatives for lower levels of testing. If no further definition of the supported equipment can be made available, this level of information will enable component/module breakdown estimates to be made by an engineer who is familiar with similar existing equipment.

(5) Equipment/Component Breakdown - At this level, the hardware configuration of the supported equipment will start to be defined. For equipment in the planning phase, it is unlikely that this level of definition will exist, except as similarities to existing equipment. During the Concept or Advanced Development Phases, this information can be synthesized, but changes (20 - 50 percent) can be expected during the Validation or Engineering Development Model Phases. Generation of this information will enable medium confidence level synthesis of alternative ATE configurations suitable for module level repair.

(6) I/O Parameter and Operating Tolerances - The input/output parameters and operating tolerances for equipment components and modules are necessary for synthesis to a high confidence level of ATE to the repair level. This information will define measurement and stimulus requirements and accuracies. Equipment would have to be well along in design, perhaps 75 to 100 percent complete, before reliable component operating parameters could be available. Obviously, it is highly improbable that these details would be known for new developments during the ILS concept definition period, except on the basis of close similarities to existing equipment.

(7) Mechanical Layouts and Schematics - Mechanical layouts and schematics are essential to the design of ATE interface hardware internal to the supported equipment, including external adapters, tees, connect/disconnects, and the ATE interface. This information will only be available on existing designs. However, for planning and costing of alternative ATE configuration for new development, it should be possible to estimate these items based on past experience. The estimating errors may be high but should not be significant in the overall cost context.

(8) Availability of Information - There is a high probability that the first four of the seven levels, (that is, down through functional descriptions) of supported equipment definition previously discussed will be available during the ILS concept definition phase of a new equipment. By the time the remaining three levels have been determined, the ILS concept will already have been defined, and the supported equipment will be heavily into the Validation Phase.

3-6.3 DEFINE TEST EQUIPMENT ALTERNATIVES

3-6.3.1 General

For each alternative maintenance concept there may be more than one test equipment alternative. An extensive vehicle installation where repair to the component level is being considered could include an ATE to fault isolate to the component, and a separate tester to locate the faulty part in the component. A single ATE system could also handle both levels, or a separate tester could be used in conjunction with BITE to locate the faulty component. Possibly, the faulty component could be located by manual methods, aided by convenient access to test points.

The total number of ATE alternatives need not increase proportionally to the number of maintenance concepts. A considerable degree of ATE commonality can exist among maintenance alternatives. Identical testers could be proposed for use at DS, GS and at the depot.

Figure 3-7 outlines the process for defining test equipment alternatives. The process can be iterative, as shown, with feedback which can alter the original maintenance concept. Although this portion of the procedure is concerned with ATE selection during the ILS/maintenance concept definition phase, the same sequence of tasks, but in much greater depth, is required further along in the acquisition of the supported equipment.

3-6.3.2 Generic ATE Types

The first step consists of proposing generic ATE types compatible with the particular maintenance alternative under study. The range of ATE types will depend as much on the type of equipment to be supported as it will on the maintenance alternative. A wide range of options is open (and necessary) for systems consisting of a number of equipments, as compared to individual equipments. The possible generic ATE options for a system can be made up from one or a combination of the following:

(1) Built-in test equipment (BITE)
(2) Other on-line test systems
(3) Off-line test systems
(4) Component testers

In addition, the generic ATE options above can each be further broken down into one or a combination of the following optional operational modes:

(1) On-line (noninterference with equipment operation during test)

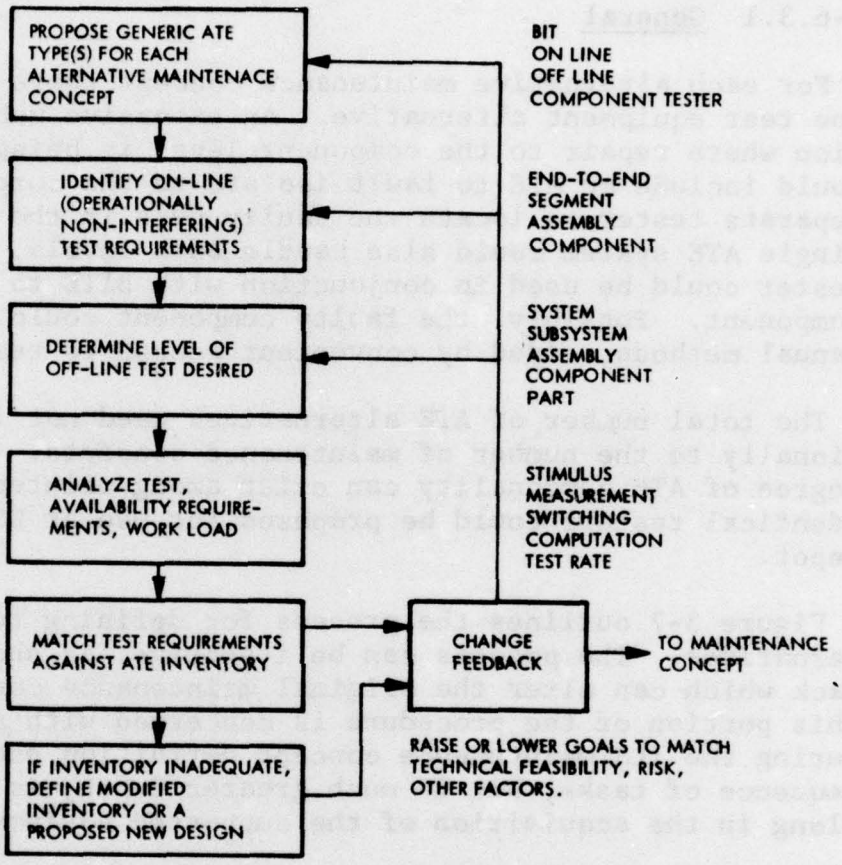


Figure 3-7. Process for Defining Test Equipment Alternatives

(2) Off-line (opposite of on-line)
(3) Performance monitoring (end-to-end test)
(4) Various fault-isolation levels - segment, assembly, component, part.

3-6.3.3 Identify On-Line Test Requirements

The mission will have to be analyzed to determine the need for on-line monitoring. From an operational and maintenance viewpoint on line monitoring (or testing) is the most desirable mode of operation. However, cost and technical considerations could require that on line monitoring be limited to mission-critical parameters. On-line testing can be specified for end-to-end, segments, assemblies, and even components where it is technically possible.

3-6.3.4 Determine Level of Off-Line Test Desired

Many of the comments made regarding on-line test requirements are also applicable to off-line testing. The major difference is that the lowest level of fault isolation - down to the part - can be specified with a much higher degree of confidence for off-line test equipment operating in an off-line mode than for on-line configurations. The degree of fault isolation attainable in off-line operating modes has so far tended to be least on BITE, increasing with centralized external test systems, and achieving a maximum on depot type test sets or component testers. Exceptions are possible in individual cases, but a thorough technical understanding of the equipment to be monitored and of ATE technology is necessary to avoid over-specifying test requirements.

3-6.3.5 Analyze Test, Availability Requirements, Workload

To analyze test requirements in detail sufficient for precise specification of ATE and its software requires information on the supported equipment which will not be available until it is almost completely designed. Therefore, until that time, this step will have to rely very heavily on the judgment of an ATE specialist who is also familiar with the proposed design of the equipment to be supported. As previously mentioned, new vehicles will use significant amounts of hardware already in inventory. However, BITE and centralized testing (except on a gross end-to-end basis) will usually be ruled out for existing equipment because of the high cost of modification for either test approach. Centralized testing, which requires the lesser modification, still requires an often costly and space-consuming integral interface. For those equipments it will be possible to determine detailed test requirements for maintenance levels where off-line ATE can be used. Equipment still in the planning stage will require the ATE specialist's judgment to identify stimulus, measurement, switching, and computational requirements, and these obviously can enable ATE specification to the A level (MIL-STD-490) at best, because of the preliminary state of the equipment design.

The desired impact of ATE on MTTR must also be analyzed. This will require acquisition of projected reliability, maintainability, and availability data.

In effect, a figure will be derived which states the turnaround time for equipment to be processed through an off-line ATE installation. (The time to detect faults with BITE or other on-line ATE is usually negligible.) A total workload can then be

determined by adding individual processing times for each component. The result will be an indication of desired test rate, which, because of set-up and other irreducibles could require a number of identical test systems or a mixture of different types (e.g., ATE plus x component testers).

3-6.3.6 Match Test Requirements Against ATE Inventory

At this point a set of test requirements will exist. The level of detail will depend on the depth of technical information available on the supported equipment, the time available to assemble the test requirements, and the judgment (and prescience) of the ATE specialist. If a data bank exists to describe current ATE inventory, the test requirements should be in the same format to facilitate comparison of requirements with available capability. This comparison can be done by the specialist, or, if the complexity of the task warrants the cost of automation, it can be done by a computerized data bank and a comparison algorithm. The results of the comparison will fall into the following categories:

(1) Location of one or more candidates
(2) Identification of one or more near matches
(3) Nothing suitable in inventory

When a comparison of test requirements against ATE inventory discloses nothing entirely suitable, the ATE specialist has several choices. He can locate the best match to his requirements and consider modifications to the inventory item to eliminate the shortcomings. He can accept the inventory ATE as is and reduce his requirements. He can specify an all-new design. Even when a suitable ATE is found in inventory, a new or modified design might also be considered because of cost, size, over-capability, etc.

3-6.3.7 Change Feedback

At this point a number of ATE candidates exist. They have yet to be evaluated, and a final selection made. However, the degree to which the originally proposed generic types and test requirements are technically feasible will at least be apparent. Original goals can then be raised or lowered to minimize risk and more closely to match technical realities.

3-6.4 SELECTION OF TEST EQUIPMENT FROM ALTERNATIVES

The basic evaluation criteria for selecting an ATE system for a particular maintenance concept are cost and supported system/equipment availability. There are many factors to be considered

in a trade-off. These are tabulated in Figure 3-8 and are amplified in following sections. Each factor must be weighted by the

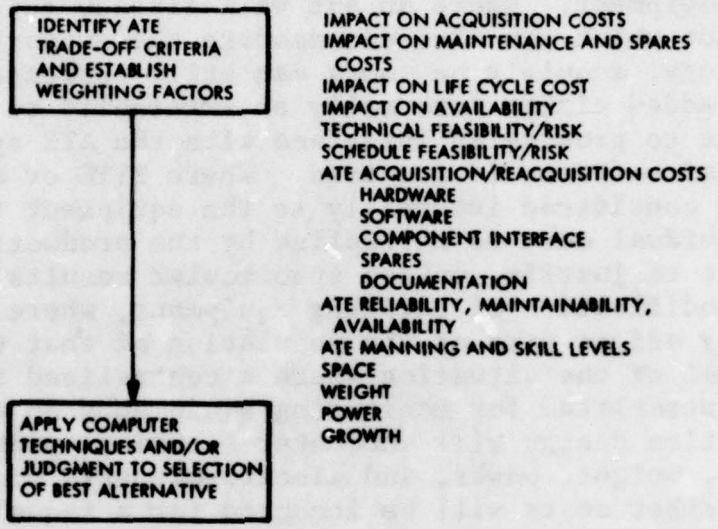


Figure 3-8. Selection of Test Equipment From Alternatives

evaluator to suit the particular application. The Army Project Manager has the ultimate responsibility for cost, system availability and performance and should be heavily involved in the evaluation. The procuring agency/project manager can best determine how much it can pay for a given increase in availability, or for future growth capability, or how acceptable a proposed increase in acquisition cost may be for a projected life cycle cost saving. Evaluation of technical risks and the creation of work-around paths will require the combined technical and management ingenuity of an ATE specialist and contractor project personnel.

3-6.4.1 Impact on Supported Equipment Costs

The introduction of ATE will result in individual positive and negative impacts on supported equipment costs. Where the net impact is an increase, the ATE alternative will be acceptable only if a compensating advantage can be demonstrated. In the case of complex systems, the incorporation of on-line test and monitoring will undoubtedly increase the system acquisition cost but without it, availability will be unacceptable. A description follows of supported equipment cost categories which can be influenced by ATE alternatives.

3-6.4.2 Acquisition Cost

ATE will drive the acquisition cost of supported equipment upward when ATE must be specially procured or built-in to the supported equipment. Where an ATE will already exist for use elsewhere, but which can also accommodate the supported equipment under study, acquisition costs can still increase if hardware must be added either internally or externally to the supported equipment to provide an interface with the ATE system, or where additional software is required. Where BITE or an ATE interface is being considered internally to the equipment to be supported, the individual cost is multiplied by the production quantity. Difficult to justify, unless spectacular results are indicated, is the modification of existing equipment, where the modifications will only affect part of the population of that equipment. This is typical of the situation where a centralized test system is being contemplated for monitoring equipments on an aircraft. The modification design will encounter technical problems in the way of space, weight, power, and electro-magnetic compatibility. Then, further costs will be incurred for a requalification program and a new documentation and spares package to support what might end up as a new equipment designation.

ATE can also drive acquisition cost downward, when improvements in availability accruing from use of ATE can reduce the need for redundancy, or reduce the production quantity originally planned on the basis of a longer MTTR without ATE.

3-6.4.3 Maintenance and Spares Costs

ATE will tend to reduce maintenance and spares costs. Maintenance manpower skill levels will be reduced by more rapid automatic detection and isolation of faults, which reduces the time and simplifies the task of repair. Spares costs can be reduced by isolating faults to a level which might be impracticable to achieve manually, thus reducing the complexity of the spares to be stocked. Further cost savings can be effected by shortening the turnaround time through the use of ATE at the depot or field facility, thus reducing spares, pipeline times, and quantity required.

3-6.4.4 Life Cycle Cost

Life cycle cost calculations will include all costs, including related ATE costs, to acquire and support the equipment for its estimated life. ATE will tend toward reducing life cycle cost

because of maintenance savings. However, this must be balanced against ATE costs. The value of improvements in availability are difficult to quantify unless a clearly identifiable reduction in supported equipment production quantity can be identified from the use of ATE. However, value should be placed on availability improvements when considering life cycle cost. There is an obvious credibility problem in balancing acquisition cost increases against life cycle cost reductions. The case for such an increase must be clear and have factual back-up. The agency responsible for the acquisition budget may be reluctant to support an increase now in exchange for a saving in the future, when the future saving will accrue to another agency.

3-6.4.5 Direct ATE Costs

If an ATE is located in inventory which meets requirements, its reacquisition cost will have to be estimated. If the ATE is no longer in production, the hardware acquisition cost can far exceed the original manufacturing cost because of start-up and inflation costs. A new ATE can be estimated on the basis of cost information for existing ATE, modified by inflation escalation factors and allowances for new technology. Software costs will also need to be estimated. Software cost can vary considerably from machine to machine for a given component to be tested. The existence of software preparation aids, such as compilers and standardized languages, are potential means for reducing the cost of preparing individual programs. The creation of software aids is usually very costly, as compared to almost any test program. A rule of thumb sometimes used today is to estimate $200 per test, where a test is defined as a stimulus-response combination or a comparison-go/no go decision. Digital test programs currently can be reduced to less than $50 per test using automatic test program generation methods. These methods utilize a computer to determine the input and response points which must be activated and monitored to test a particular digital logic circuit.

The component interface can be a significant cost item. For off-line ATE, the interface usually consists of a connecting cable and usually an adapter box or fixture. The adapter box will include dummy loads and sometimes considerable electronic gadgetry which is too special in nature to warrant integrating into the ATE. A minimum interface, then, could cost under $1000. The maximum can run as high as the benefits will justify - easily into the thousands of dollars.

Support costs in the way of spares, documentation, and maintenance manning requirements for ATE should also be considered.

3-6.4.6 Technical Evaluation Factors

The following technical factors should be considered in evaluating an ATE:

(1) ATE RMA Figures - The ATE RMA figures are important evaluation factors. A complex ATE is subject to the same statistical reliability hazards as a complex supported equipment. The difference is that a self-test function is inherently easy to build into ATE. Reliability and maintainability will influence maintenance manning costs, previously mentioned. They will also determine availability and, therefore, work turnaround or flow rate.

(2) Technical Risks - The technical risks must also be evaluated. An over-ambitious set of technical requirements could result in technical problems which are impossible or impracticable of solution because of time, money and state-of-the-art constraints. Where a serious risk is recognized, requirements may have to be reduced. Where the risk is marginally acceptable, an escape route should be plotted which will allow for a change of plan just before the point of no return.

(3) Physical Characteristics - Space, weight, power and power requirements for ATE can vary from trivial to extremely important evaluation criteria. The weighting factors obviously depend on the application.

(4) Growth Capability - Growth capability, or flexibility, defined as capability in excess of current needs or as provisions to facilitate future expansion, can also be an evaluation criterion. However, this factor is largely subjective when it comes to placing a dollar value on it.

(5) Test Spectrum - From an analysis of prime equipment test requirements, a spectrum is generated of test stimuli and measurements. From this listing, a data bank can be scanned for candidates in existing inventory.

(6) Environment - Although the acceptability for Army use of high grade commercial ATE is growing, there are still applications which demand design to the more stringent MIL environmental requirements. Environmental specifications are, therefore, an important technical evaluation factor.

(7) Availability/Risk - The extent to which candidates are available, or the risks of developing new ATE are factors to be considered. There is even a risk in re-procuring previously designed ATEs if not presently in production, in that a significant start-up cost could be encountered or technological obsolescence could make components difficult to procure. Available software versus the risk of developing new software must be considered in view of the length of time and cost to develop software.

It is possible to develop evaluation equations by assigning values and weighting each factor. Weighting will depend on individual applications and may contain a high degree of subjectivity. Cost factors can be used without any manipulation, and rough benefit/cost ratios can then be developed by dividing the summation of weighted benefits by cost for each alternative. Evaluation factors may be used individually for screening purposes, eliminating ATE candidates for such reasons as being too large for the available space, too costly for the available funds, or incapable of meeting environmental requirements. Figure 3-9 summarizes evaluation factors and the methodology for their use. Evaluation is seen as a sometimes iterative process, wherein compromises in ATE requirements may be compelled by technical and fiscal realities.

Technical evaluation factors are useful for initial screening purposes. Later in the evaluation process, if otherwise attractive candidates are identified which do not quite meet all technical evaluation factors, then technical factors may be assigned values and weighted for use in a trade-off process.

3-6.4.7 Performance Evaluation Factors

Some performance evaluation factors are also technical in nature but at a system level and are therefore treated separately from detailed technical evaluation factors:

(1) Performance - Measures of ATE performance are monitoring and fault isolation levels, test rates and results formats. For some applications, the allocation of on-line and off-line test tasks may also be of significance.

(2) Availability - Availability evaluation factors for the ATE involve MTBF, MTTR, and calibration requirements. Consideration is required of the level and speed of self-test, and the relative degree of in-place calibration versus calibration requiring component removal.

(3) Logistics Factors - Logistics factors are at least as important for the ATE as for the equipment it supports, since prime equipment availability can depend heavily on its ATE. Logistic factors consist of personnel, training, spares, calibration facilities, and support documentation. Operational and maintenance crew size and skills need to be identified. When tests will call for operator intervention in the test cycle, as often encountered with off-line depot testing, the operator may need training in the operation of the component to be tested as well as in ATE operation. Spares levels, locations, and pipeline times are significant factors. The location of the calibration

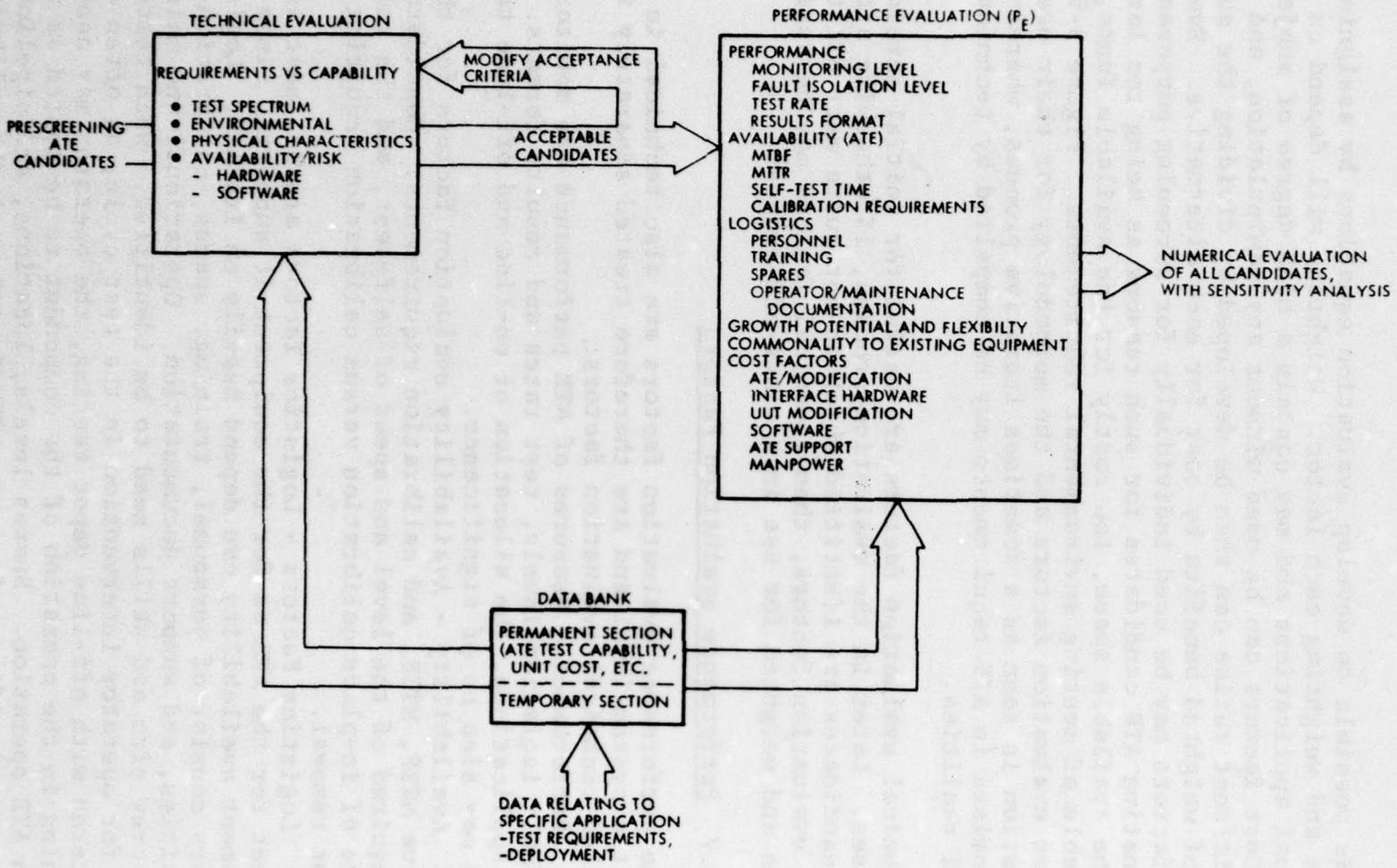


Figure 3-9. ATE Evaluation Methodology

facility and any special equipment for that purpose should also be identified.

(4) Growth Potential and Flexibility - These factors break down into excess technical requirements and capacity, and design flexibility. The evaluator must decide what these factors are worth to him, and to do so, he has to estimate future needs. Technical requirements in excess of presently known needs may be sought to handle additional component types, or in anticipation of possible design changes to existing components. Excess test rate capacity may be desirable to allow for component operational MTBFs which may be lower than predictions, or in anticipation of additional support requirements from other causes, or simply, as a conservative allowance for ATE or personnel performance which may not come up to expectations. Flexibility of design is related to excess technical requirements. It is desirable as a means for avoiding early obsolescence, and to meet supported system changes. Flexibility of design will facilitate establishing expanded or contracted configurations to serve a variety of applications from one design family.

(5) Commonality Factors - Related to logistics and flexibility factors are commonality factors. It is clearly desirable for an ATE to use a minimum of newly designed assemblies. The ATE could use assemblies from another ATE or from the prime equipment, as in the so-called "hot mock-up" type of special test sets.

(6) Cost - Cost factors dominate any ATE evaluation, and will continue to do so. Costs go beyond the ATE itself and can be significant where supported equipment must be modified for compatibility with the ATE. It has become well-known through disillusioning experience that software costs can exceed hardware costs in some applications. As with any other equipment, documentation costs for ATE can also be significant. Acquisition costs and life cycle costs may have to be separately considered. Figure 3-10 tabulates a hierarchy of items that make up total ownership costs, and Figure 3-11 separates acquisition, application, and usage costs. A listing of cost factors follows:

(7) ATE Acquisition/Re-acquisition/Modification Costs - Is new ATE to be required? Existing ATE to be re-acquired? (Beware of start-up and inflationary escalation.) Can existing ATE be used or re-acquired with modifications to do the job?

(8) Component/ATE External Interface Hardware - These are the adapter boxes and cables used between components being tested and the ATE. Although potentially a costly item (and a storage and retrieval problem), it is usually far less costly than to alter the component and the ATE to eliminate the need for them.

(9) Component or Unit Under Test (UUT) Modification - UUT modification should be examined with care. A simple UUT modification

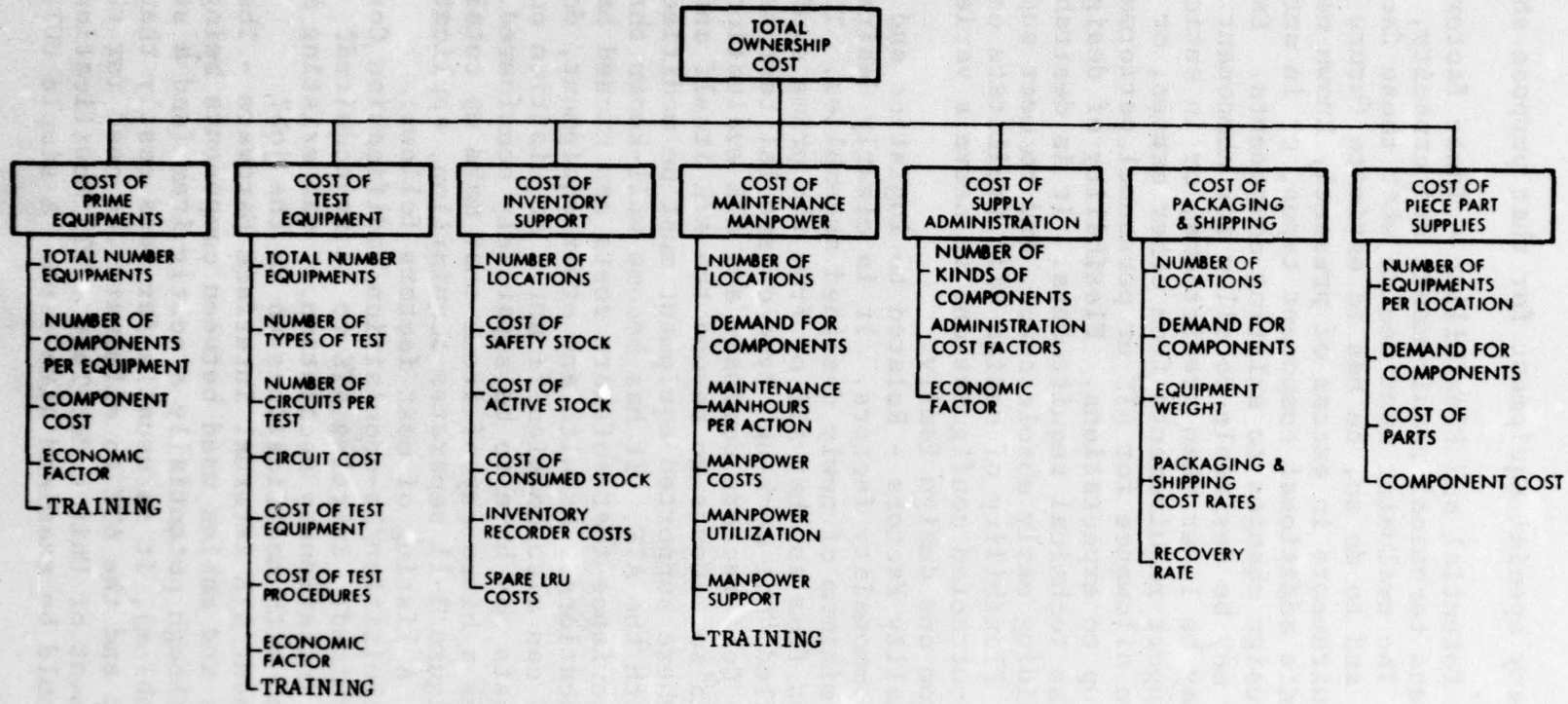


Figure 3-10. Major Factors Contributing to the Cost of Ownership

$ COST TO BUY IT	$ COST TO APPLY IT	$ COST TO USE IT
HARDWARE	HARDWARE	
Test System(s)	Interface Devices	Spare Parts
Peripherals	Adapters	Software Maintenance
	Modifications	
Power		Operator/ Maintenance Personnel
Facilities		
(Screen Room, A/C, Etc.)		Calibration
		Facility Overhead
SOFTWARE	SOFTWARE	
Compilers	Test Programs (Design & Validation)	
Executives		
Routines	Test Generators	
Simulators	Self Test for Adapters/Inter-face Devices	
Program Manuals		
Operator/Maintenance Manuals	Updated Program Manuals	
Self Test Programs	Operator/Maintenance Training	

Figure 3-11. Resources Required - Dollars

to provide compatibility with ATE can be accompanied by a major documentation and spares provisioning change. This is particularly significant where only a portion of the UUTs will be so modified, leading to a possible nomenclature change and requalification.

(10) Software - Costs are incurred in preparation of UUT test software, ATE self-test software, software preparation aids such as compilers and assemblies, and in maintenance of software as UUTs change.

(11) ATE Support - The ATE will need support funding for spares, special test or calibration equipment, and operational and maintenance documentation.

(12) Manpower - Training, salaries, and traveling costs of the operational and maintenance crews are a factor.

(13) Physical - Costs for real estate or storage space, power, and other physical plant facilities should be identified.

3-6.4.8 Quantification of Evaluation Factors

In order to minimize the subjectivity that is inevitably part of any equipment trade-off, attempts should be made to assign numerical values to evaluation factors. Certain factors are normally expressed in numbers, and they should be used as such with weighting constants used to match particular applications. Factors which are normally expressed numerically are:

(1) Costs
(2) Testing rate, UUT and self test
(3) Availability
(4) MTBF
(5) MTTR
(6) Maintenance man hours per operating hour
(7) Operating man hours per operating hour
(8) Space
(9) Weight
(10) Power
(11) Environmental specifications

Figure 3-12 illustrates in steps the acceptable level of risk on a basis of operational need date versus ATE design and production values. At one extreme, a six-month operational need date calls for selection of an ATE which is already operational and with free time to handle the proposed application. At the other end of the scale, only an operational need date more than two years away can accommodate a new ATE design as an acceptable risk.

Other factors do not lend themselves well to quantification with any degree of mathematical rigor. A case in point is "growth potential and flexibility" one of the suggested performance evaluators. Suppose that the candidate ATE stimulus spectrum exceeds present requirements. How should the excess be evaluated?

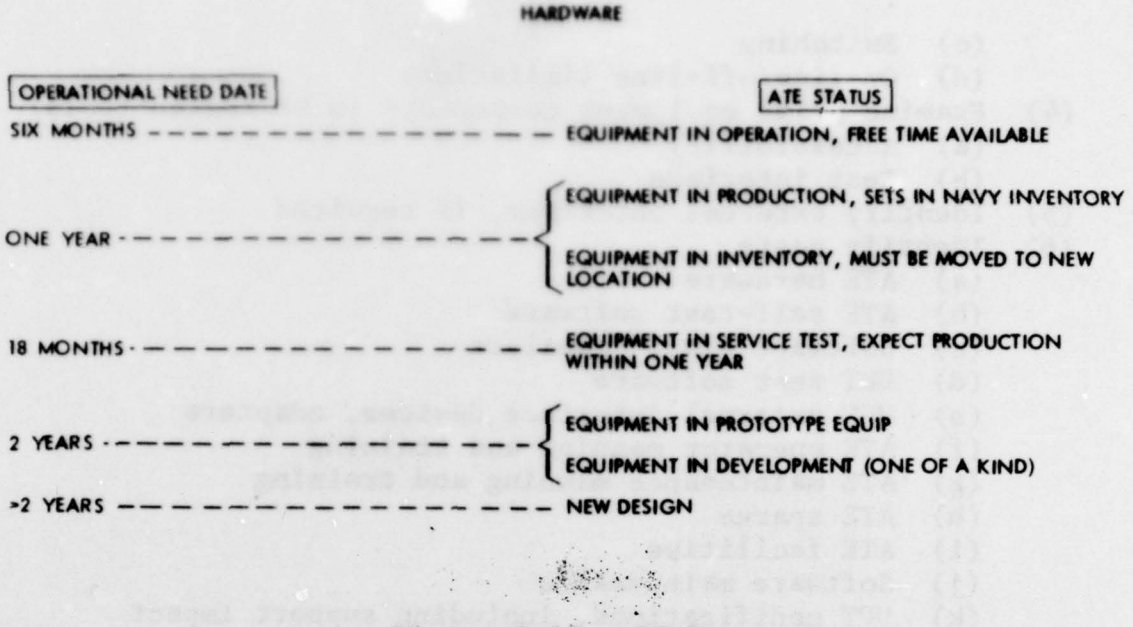


Figure 3-12. Risk

A tempting approach is to use a binary rating, with 'yes' or 'no' for the existence or absence of a factor, but obviously this leads to being able to bias the system by providing trivial advantages which will score high but possibly be of little benefit. Regardless of the obvious difficulties, an attempt should be made to attach numerical values to all evaluation factors, using whatever criteria seem suitable. The values and their weighting coefficients may be subjective and very much application-dependent, but the approach will be more useful than one which has no numerical base. Fortunately, cost, which is the most significant evaluation factor, is numerical in nature. The evaluator's only problem with costs is their credibility, and this can be handled by dividing estimated costs by their confidence factor to give a factored cost.

3-6.5 CHECK LIST

This is a list of items which should be considered in the course of the ATE selection and evaluation procedure. The list includes procedural steps, evaluation factors and prerequisite information.

(1) Obtain prime equipment descriptive material
(2) Obtain support concept description
(3) Develop test requirements listing
    (a) Stimulus
    (b) Measurement

(c) Switching
(d) On-line/off-line limitations

(4) Examine prime equipment components to be tested (UUTs)
(a) Accessibility
(b) Test interface

(5) Identify external interface, if required

(6) Identify costs
(a) ATE hardware
(b) ATE self-test software
(c) Software aids, compilers
(d) UUT test software
(e) UUT external interface devices, adapters
(f) ATE operator manning and training
(g) ATE maintenance manning and training
(h) ATE spares
(i) ATE facilities
(j) Software maintenance
(k) UUT modifications, including support impact
(l) Documentation

(7) Analyze evaluation factors
(a) Test spectrum
(b) Environmental specs
(c) Physical characteristics
(d) Design/availability status
(e) Risk
(f) Monitoring level
(g) Fault isolation level
(h) On-line/off-line capability
(i) Displays
(j) Test rate
(k) MTBF
(l) MTTR
(m) Self-test
(n) Calibration requirements
(o) Personnel skills
(p) Training
(q) Spares policy
(r) Documentation
(s) Growth potential/flexibility
(t) Commonality to existing equipment

SECTION III

ATE APPLICATIONS

3-7 EXAMPLE OF THE APPLICATION OF ATE TO A LARGE HYDRAULIC/PNEUMATIC TEST FACILITY

The Automatic Test System for Jet Engine Accessories (ATSJEA) (Reference 1) has been designed, tested and installed at two Air Force locations, Tinker Air Force Base in Oklahoma and Kelly Air Force Base in Texas. Each system comprises six test stands, and a two-computer complex with peripherals. All communication between a test stand and the computer complex is by means of a data bus. The block diagram of Figure 3-13 presents the major elements of the system with only one of the six test stands shown. The two computers are noted in the diagram as:

(1) The control processor or Central Processing Unit (CPU).
(2) The Elementary Operations Controller (EOC).

These computers perform different functions.

The CPU is responsible for interpreting program steps and issuing demands to the EOC to achieve a certain flow, pressure, speed or shaft angle. The EOC is required to translate these commands into test stand control signals and to measure the results with its pressure, flow, speed or angle sensors to assure the desired condition. These measurements are delivered to the test stand's digital display about once per second. The operator has direct access to the CPU by use of a teletype keyboard (TTY) located at the test stand.

Because the testing of a jet engine fuel control requires a source of fluid at high pressure (to 1200 PSI) and a controlled pneumatic pressure (to 450 PSI) that simulates the engine's compressor discharge pressure, these test stands are a good example of the automation of a combined hydraulic/pneumatic test facility.

Since the fuel control also requires a high speed shaft input (to 7000 RPM, but at low torque) to simulate the normal geared-down turbine input and remote positions for the power-level-shaft to various angles, a substantial mechanical automation is also involved in the test stand design.

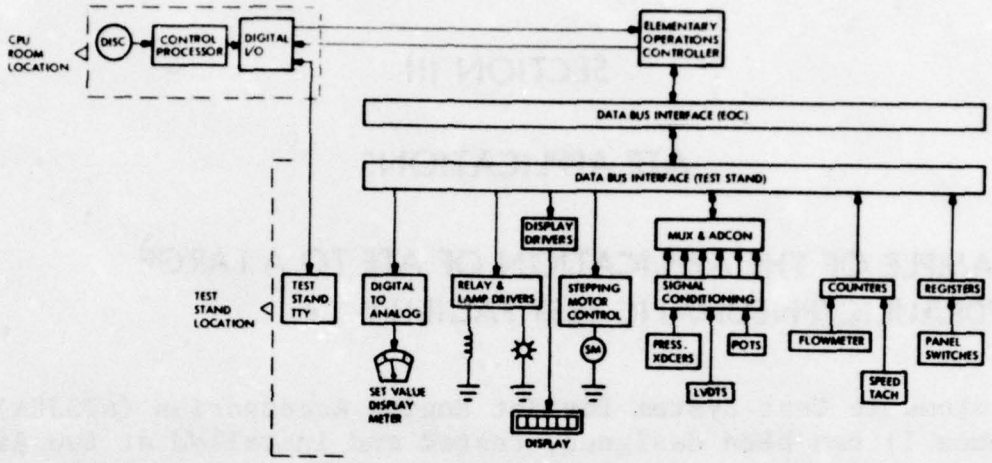


Figure 3-13. Measurement/Control Organization

Special features of these test stands are:

(1) Each test stand has the potential of testing many different types of fuel controls that fall within the range of its maximum flow and pressure capabilities. Some unique bracket design is required to fit pot pickoffs of shaft actuators to a particular fuel control type.

(2) Each test stand can be operated manually or interrupted in the middle of an automatic routine with a bumpless transfer. (No step inputs are possible. All control commands are carried out at either a fast or slow slew rate. A simple hardware modification selects these rates.)

(3) On-line programming, using the teletype in the CPU area, can proceed while all test stands are operating in a production mode.

(4) The assignment of sensors for pressure and motor or solenoid commands generally will be different from one fuel control type to another, but reassignment is readily accomplished by loading a new table controlling such assignment.

(5) Calibration tables are located separately in the EOC for each measurement device. Accordingly, no hardware calibration is required beyond assuring that the signal operates within a broad voltage range.

(6) Unlike the equivalent manual test stands, the ATSJEA test stands are all essentially identical in the area of manual controls and displays. Accordingly, an operator trained on one is quite capable, without additional extensive training, of operating any other.

3-8 EXAMPLE OF THE APPLICATION OF ATE TO AN AUTOMOTIVE TEST SYSTEM

The Automated Test Equipment for Internal Combustion Engines (ATE/ICE) is a computer-controlled system using certain simple measurement parameters on a vehicle to accomplish diagnostic tests of the major engine components. Descriptions of the transducers and their functions are presented in Table 3-1. The system contains operational modes shown in Figure 3-14. The function of each mode is listed below:

(1) Confidence, a self test feature of the signal processing components of the ATE/ICE.

(2) Auto Inspection, which the ATE/ICE uses to prompt the mechanic on pre-operational visual inspection.

(3) No Start, selected if the engine refuses to start.

(4) Performance Test, provides for the automatic testing of numerous subsystems as outlined in Figure 3-15.

(5) Provides a much shorter routine to monitor the usual components involved in an engine tune-up.

3-9 TEST QUALITY IMPROVEMENT USING ATE

One of the more surprising results of the substitution of ATE for previously manual testing in one large installation (four automated test stands) was the improvement in the acceptance rate for the article being tested. In this case, jet engine fuel controls were being adjusted and checked for accuracy before further testing on the engine in an engine test cell. It was the custom of some operators on the manual test stands to use their judgment in deciding whether a fuel control was acceptable, even though it might not have adhered strictly to the pressure/flow profiles required by the test procedure. Indeed, in some cases, it was found that the operator was not recording hard data during the test procedure, but was filling in the many blanks in the data sheets from memory with fictitious data so that the test results would be within the known limits. As a consequence, a high percentage of fuel controls leaving the manual calibration test stands were being rejected during the subsequent expensive tests in the engine test cell.

The introduction of ATE in the form of computer-operated test stands with their hard limits on acceptable parameter values and hard copy printout in all phases of testing eliminated this source of maladjusted fuel controls to such a degree that the rejection of a fuel control in the subsequent engine test is now a rare occurence.

TABLE 3-1. ATE/ICE TRANSDUCERS AND ADAPTERS

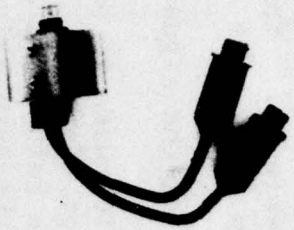
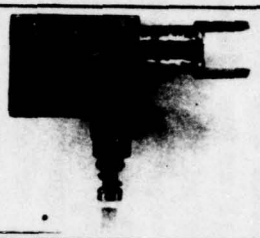
Transducer name and designator	Parameter measured/ function	Location/ description	Illustration
Ignitor Probe	Ignition primary voltage Ignition secondary voltage	Inserts in top of ignitor	 ATE/ICE-012
Crankcase Blow-by Pressure	Crankcase blowby pressure	Replaces oil filler cap on valve cover.	ATE/ICE-013
Number One Firing	#1 Firing reference	Inserts in number one sparkplug socket.	 ATE/ICE-014
Exhaust Hydrocarbon	Hydrocarbon threshold in the exhaust	Exhaust pipe	ATE/ICE-015

TABLE 3-1. ATE/ICE TRANSDUCERS AND ADAPTERS (cont)

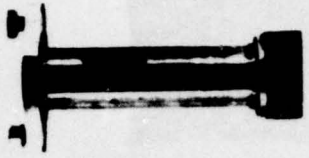
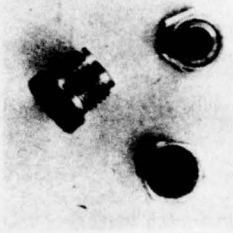
Transducer name and designator	Parameter measured/ function	Location/ description	Illustration
Exhaust Adapter	Adapt exhaust hydrocarbon transducer to exhaust pipe	Exhaust pipe	 ATE/ICE-016
Current Probe	Current (bi-directional)	On battery primary cable or as required	ATE/ICE-017
Intake Manifold Pressure	Intake manifold vacuum	Vacuum access port on top rear of intake manifold	ATE/ICE-018
Blowby Test Fittings	Crankcase seal	Block input to PCV from valve cover Block line from crankcase to carburetor. Place fixed orifice on valve cover	 ATE/ICE-019

TABLE 3-1. ATE/ICE TRANSDUCERS AND ADAPTERS (cont)

Transducer name and designator	Parameter measured/ function	Location/ description	Illustration
Ignitor Unit Adapter APN 4910-356-7508	Ignitor input voltage	Ignitor input	ATE/ICE-020
Engine Oil Temperature	Oil temperature	Replace dip stick	ATE/ICE-021
Battery Voltage	Battery voltage	Assemble on voltage limiter assembly cable ends. Attach to battery terminals.	ATE/ICE-022
Voltage Probe Adapters	Configure end of SC probe to conform with electrical device being measured.	Used wherever voltage measurements with SC probe are made. Seven different pairs of adapters are supplied. (Voltage probe is part of PDU equipment. Probe contains auto-polarity circuits permitting use of either probe end to measure voltage.)	ATE/ICE-023

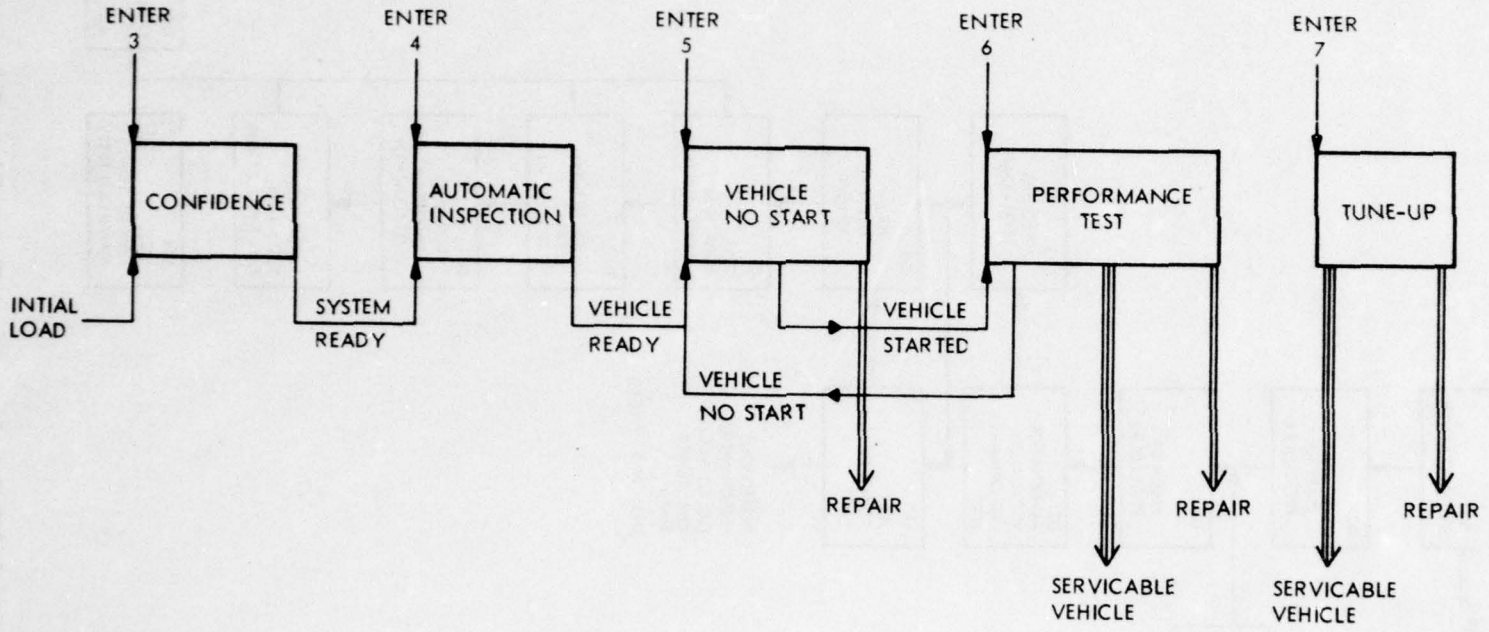


Figure 3-14. ATE/ICE Program Flow

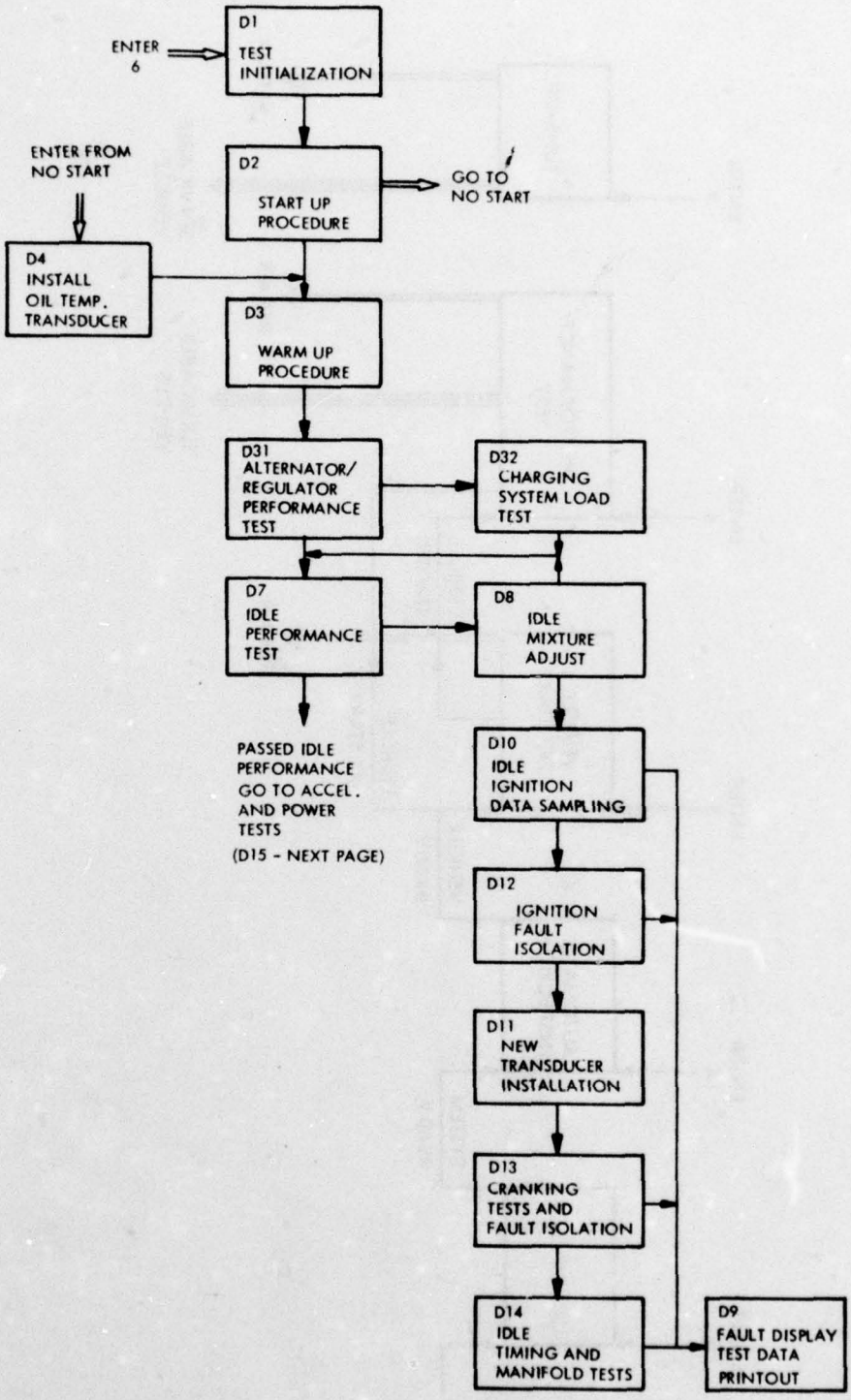


Figure 3-15. ATE/ICE Performance Test Flow Diagram, Sheet 1 of 2.

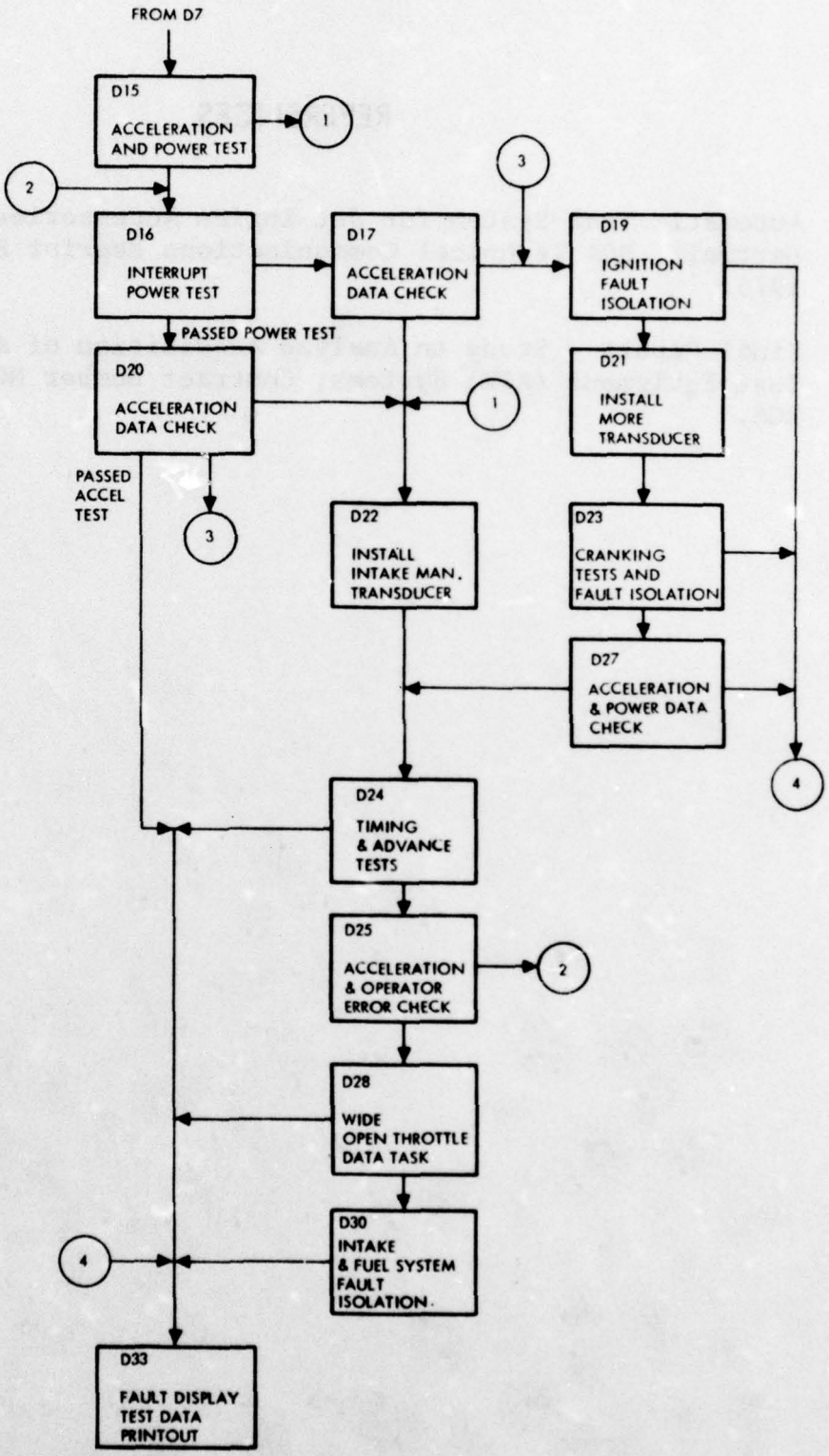


Figure 3-15, ATE/ICE Performance Test Flow Diagram, Sheet 2 of 2.

REFERENCES

1. Automatic Test System for Jet Engine Accessories, R.E. Hartwell, RCA Technical Communications Reprint RE-20-6-6, 1975.

2. Final Report - Study to Analyze Acquisition of Automatic Test Equipment (ATE) Systems, Contract Number N00123-73-C-1326, RCA.

PART II

GENERAL OBJECTIVES, PROCEDURES, AND TECHNIQUES

CHAPTER 4
MAINTAINABILITY AND TEST ACCESSIBILITY PROGRAM PLANNING

4-1 GENERAL

It is the policy of the Department of the Army (References 1 and 2), that maintainability of materiel and equipment will be achieved by:

(1) Designing maintainability into materiel rather than it being attained through subsequent modifications as a result of tests, field complaints, or product improvements.

(2) Effective planning, programming, and managerial direction.

(3) Adequate research, engineering, design, development, and evaluation.

(4) Efficient administration of logistical and operational procedures designed to preserve inherent maintainability.

(5) Establishing data sources of critical information on maintainability for design and planning activities.

The impact of this policy of the design activity should be emphasized by a carefully thought out maintenance support plan. This plan, in general terms, should indicate who will accomplish what echelon of maintenance, expected time required to accomplish the maintenance, type of test equipment to be provided, maintenance units in existence or to be organized to service or support the new equipment, and milestones to demonstrate and evaluate the validity of the plan. It is the management tool designed to identify action elements of maintenance support which require timely execution and completion by the agencies responsible for each element of maintenance support.

The maintenance support plan must be implemented and updated to run concurrent with equipment design, development, production and concept of field operation. Such a program is mandatory to meet the requirements of military specifications calling for maximum equipment availability and reduced maintenance costs.

References 2 and 3 provide the policies and the assignment of responsibilities for integrated maintenance support planning, for the preparation of maintenance support plans and logistical support plans, and for the coordination and distribution of these plans by the preparing agency. As defined by these documents the elements of maintenance support are:

(1) Trained military and civilian maintenance personnel.
(2) Requirements for new or changed military and civilian skills.
(3) Military and civilian instructor and operator personnel.
(4) Repair parts.
(5) Special and common tools and test equipment.
(6) Support and ground handling equipment.
(7) Technical manuals.
(8) Technical assistance.
(9) Maintenance load.
(10) Modification work orders.
(11) Calibration.

Maintenance support plans should be prepared for each supportable end item or weapons system of new materiel which will be issued to troops and which is not covered by an adequate, previously published maintenance support plan or Department of the Army equipment manuals. A sample format, showing the major action elements which must be considered in the preparation of the Maintenance Support Plan, is shown in Figure 4-1.

4-2 PURPOSE OF THE MAINTAINABILITY/ACCESSIBILITY PROGRAM PLAN

The purpose of the maintainability and accessibility program plan is to ensure that a system or equipment will be designed to meet the specified maintainability requirements in an effective, timely, and economical manner. It provides for a systematic analysis of the maintainability effort and gives guidelines for meeting or exceeding the specified requirement. To be effective, the maintainability program must be integrated with the system/equipment design engineering program to assure effective, timely, and economical accomplishment. The program should be consistent with the type and complexity of systems or equipment and phase of the acquisition and shall ensure attainment of the contractual maintainability requirements. The essential tasks that the program plan should address are shown in Table 4-1. The maintainability program plan contents are shown in Table 4-2.

SCHEDULE OF MAINTENANCE SUPPORT PLANNING

Overall MSP ☐ Annex to MSP ☐

1. Nomenclature		2. Date of Schedule	
		a. Date [1] of Initiation	b. Date [1] of Completion
3. MSP:—No. —Schedule for First Draft			
Major Action Element			
4. Qualitative Materiel Requirement (Maintenance Input) 5. Maintenance Concept Established 6. Reliability and Maintainability Data Collection 7. Technical Documentation Data 8. Maintenance Evaluation 9. Special Tools and Test Equipment for Service Test (Organizational, Direct, and General Support) 10. Repair Parts for Service Test 11. Draft Technical Manuals 12. Key Personnel Training Civilian Manpower Requirements 13. Service Test (Agency(ies)) 14. Maintenance Literature Finalization Conference 15. Type Classification (Type)			
Repair Parts	16. Selection of Range and Quantity		
	17. Identification by FSN		
	18. Procurement		
	19. Available for Issue		
Technical Manuals	20. Operators		
	21. Organizational Maintenance		
	22. Direct and General Support Maintenance		
Special Tools	23. Procurement		
	24. Available for Issue		
Test Equipment	25. Procurement		
	26. Available for Issue		
Equipment Special Calibration	27. Procurement		
	28. Available for Issue		
29. Technical Assistance 30. Production Rolloff 31. Issue to Troops 32. Overhaul Standards and Procedures			

1 Forecasted dates will be preceded by the letter "F."

Figure 4-1. Sample Format for Preparation of Maintenance Support Plan

TABLE 4-1. MAINTAINABILITY AND ACCESSIBILITY (M/A) PROGRAM PLAN TASK CHECKLIST

- M/A Program Plan
- Design Review
- M/A Allocations
- M/A Reports
- Trade-Offs
- Special M/A Analysis
- Maintenance Concept
- GFE Integration
- M/A Design Criteria and Specification Inputs
- M/A Predictions
- M/A Design Audit
- M/A Demonstration Plan
- M/A Demonstration-Conduct and Report
- M/A Data Collection Analysis and Corrective Actions

TABLE 4-2. CONTENTS OF MAINTAINABILITY AND ACCESSIBILITY PROGRAM PLAN

- Work to be accomplished under each task
- Time phasing of each task
- Contractor organizational element responsible for implementing the maintainability program
- Lines of communication between the contractor organization responsible for implementing the maintainability program and other contractor interfacing organizations
- Appropriate customer-contractor program milestone review points
- Specific technique(s) for allocating quantitative requirements to lower level functional elements of the system (group, unit, assembly, subassembly, etc.)
- Specific technique(s) for allocating test points
- Specific technique(s) for maintainability predictions of quantitative requirements at lower level functional elements of the system
- Interfaces between the maintainability program and other closely related programs (logistics, reliability, safety engineering, etc.)

4-2.1 COMPLEXITY OF THE MAINTAINABILITY AND ACCESSIBILITY PROGRAM PLAN

The maintainability and accessibility program must be consistent with the type and complexity of the system or equipment and be integrated with the entire design engineering effort. The program plan provides the contractor with a means for showing how he expects to tailor the maintainability/accessibility program to meet these requirements in an effective, timely, and economical manner. In describing the planned interfaces between the maintainability and accessibility program and other closely related programs or efforts listed in the standard, there need be only enough information to show that duplication of effort will be avoided and continuity between interrelated functional responsibilities, irrespective of organizational boundaries, is assured. Thus, the plan should be flexible with regard to what portions of the plan become part of a full-scale development contract. The plan may be contracted for in whole or in part, depending upon mutual agreement between the contractor and the procuring agency. It is important to assure that necessary basic tasks are properly interpreted and mutually understood, to give the procuring activity confidence that maintainability and accessibility requirements will be met at the end of the Full-Scale Development Phase. At the same time, this gives the contractor the flexibility he needs to avoid the necessity for formal changes in the future.

The requirements for a maintainability program plan apply to the development of all systems and equipment subject to validation. When validation is not involved, the extent of a maintainability program plan's applicability should be specified in the Request for Proposal or Contract Work Statement, or both.

4-3 RESPONSIBILITIES OF THE PROCUREMENT AGENCY AND CONTRACTOR

The successful implementation of test accessibility depends on a strong maintainability program which incorporates appropriate accessibility considerations. A sizable amount of effort is required on the part of procurement agency and contractor managements to assure success. Their responsibilities are key in the proposal phase and in the design phase.

4-3.1 PROPOSAL PHASE CONSIDERATIONS

A brief statement of procurement responsibilities form a necessary base from which to view the role of the contractor. The procurement agency engineering group responsible for preparing the RFP technical specification for new equipment has a difficult task

in precisely defining test accessibility requirements and responsibilities. The task is simpler for built-in test where at least the responsibility resides entirely with the prime equipment designer. Still, the agency must clearly define the BITE function. Specifying fault isolation to a particular component level is a solution which neatly ties the task to the maintenance echelon of interest. However on large equipments, the components are often partitioned by splitting and combining different subfunctions in each system as a device for achieving standardization and saving space. Unfortunately, this approach also encumbers test accessibility. A compromise solution is to specify fault isolation not to an individual component assembly, but to some average number of components with adequate safeguards against excessive deviations from the average. As an example, built-in fault isolation could be specified on a large system to an average of three components in a functional area. A separate off-line portable tester could then be used to locate the one faulty component.

The procurement problem presents a different aspect when separate manufacturers are used for test and prime equipment, as is almost always the case for general purpose ATE, and where difficult choices must be made in allocating responsibilities between manufacturers. Possible incompatibilities arise from the electrical interface, the choice of test points, and the availability of the information needed by the test program designer.

Interface incompatibility can be avoided by disseminating a thorough definition of the ATE interface to the prime equipment designer and requiring him to meet that interface within his equipment. Alternatively, an interface adapter can be created between the two equipments. This may be the preferred approach with mechanical, hydraulic and pneumatic systems where design would be needlessly complicated by the integral addition of signal conditioners. The interface adapter box is economically attractive with external test equipment which will be used occasionally, where the cost of the adapters to go with each test set would be far less than that of the sum of the signal conditioners needed at each of the more numerous equipments to be tested. The ATE contractor may be a better choice than the prime manufacturer for design of the adapter box, since he would be expected to have built up an extensive background in similar devices.

The selection of test points must be an integral part of the prime equipment design, and the risk is that the designers may lack the necessary test orientation to select the proper ones. The major safeguard against that happening is a careful review of the proposals during source selection to determine whether test

accessibility is planned to receive the necessary attention. Further assurance of the optimum selection of test points can be provided by test compatibility design reviews attended by members of the prime and ATE design organizations and chaired by the procuring agency.

Test programming can be assigned either to the prime or the ATE designer. Either way there is a risk. The prime is not likely to be as test oriented or as experienced as the ATE designer in writing and validating programs. On the other hand, the detailed performance information needed by the ATE test programming contractor will usually only be made freely available by the prime designer if his contract clearly assigns to him the responsibility for supporting test programming. Here, too, the customer-chaired design review process can help assure the desired cooperation between both contractors.

4-3.2 DESIGN PHASE CONSIDERATIONS

There is a natural tendency on the part of design engineers to resist improved test accessibility. Their first responsibility is to design equipment which performs a task, and test accessibility provisions often appear to interfere with the orderly accomplishment of the prime task. For mechanical equipment it may mean having to add mounting pads for sensor installation, inserting taps for pressure monitoring, placing sensors in difficult locations and providing wiring to them which is immune to the grease, heat, and vibration normal to the engines. If proper planning has not gone into the proposal phase, management can also find the cost of test accessibility painfully higher than they had originally supposed.

Generally, management should see that their design teams are properly oriented toward the importance of logistic requirements and the impact of test accessibility on those requirements. One device for achieving this orientation is to "salt" the design team with someone whose sole responsibility is test accessibility, an engineer whose job it is to think test. Obviously, the test man cannot be a figurehead; he needs the support of management above him to keep from being swamped by the design engineers' single-minded dedication to the prime functional task. Good test accessibility design requires management to take these or similar steps, monitored by a vigilant customer.

4-3.2.1 Test Methods Analysis (TMA)

The Test Methods Analysis (TMA) is performed to determine the stimulus, measurement, and test point capability required to achieve a given degree of test accessibility. The TMA on an equipment ideally requires the following data:

- Detailed description of equipment/component
- Laboratory or factory test procedures
- Operational monitoring policy
- Maintenance policy at each echelon
- Complete description of test equipment.

4-3.2.2 Component Related Data

The equipment under test description is needed to define the hardware to be tested and to provide clues as to where test points should be located. Since the equipment definition will normally be in a state of flux during the design phase, the test analyst must work with preliminary and constantly changing data. Laboratory or factory test procedures will usually not become available until very late in the design phase; however, where they do exist, they considerably simplify the TMA task by suggesting a stimulus, measurement, and test point configuration which may turn out to be very close to what is needed for maintenance testing.

4-3.2.3 Operational and Maintenance Policies

Unless previously defined during the proposal phase, operational and maintenance policies will be mutually determined by customer and contractor during design. Operational policy will specify the degree of overall confidence testing to be performed by the equipment operator, and whether built-in or external means will be used for that purpose. Maintenance policy will be based on logistic requirements and will determine for each maintenance echelon the repair and related fault isolation levels, and the degree of disassembly permitted at each echelon. Test point accessibility must be consistent with the permissible degree of disassembly. At forward echelons this is apt to require externally accessible test points or BITE. Rearward toward the depot, internal probing of test points becomes more practicable. However, if ATE is used, its high test speed and relatively lower operator skill requirements may make unacceptable the lost time and potential hazard, respectively, of disassembly and direct probing.

4-3.2.4 Test Equipment

The test methods analyst needs to know the capability of the test equipment with which his equipment will operate. Where the test equipment has been specified, the task is simple. More often, the test equipment is identified as an output of the TMA rather than as an input. In the future, with increasing application of multi-purpose ATE, there will be a correspondingly increasing tendency for the customer to specify the test equipment. Where standard manual test equipment is all that is available, the analyst should facilitate future ATE applications by specifying items for which equivalents exist in ATE programmable form and which require minimal human interpretation of results. It is also essential that the analyst familiarize himself with current ATE techniques and configurations to ensure that he is designing in test accessibility for the future, not only the immediate present. This means favoring external test point connectors for quick access, which requires special care to ensure adequate circuit isolation while meeting external interface needs. Unfortunately, no standard ATE interface specification exists, with the exception of the Navy-developed MIL-STD-1326, which is not in general use and which covers only analog test points. In the absence of an ATE interface specification, standard manual test equipment input loadings can be used as a guide when specifying test point isolation and signal conditioning devices.

4-4 TYPICAL MAINTAINABILITY ENGINEERING PROGRAMS

In order to implement the maintainability program, the maintenance support plan must be designed to meet the following objectives:

(1) Be sufficiently flexible to permit revision and updating at any point in the program.

(2) Show the various tasks and milestones, and approximate times required to accomplish each.

(3) Show each key event, and the coordinated sequence of occurrence, and the interrelationship of events.

(4) Provide valuable impetus for determining project costs and the most economical allocation of personnel.

The key events of a typical maintainability program are presented in Figure 4-2. A brief summation of the tasks and functions of a four phase maintainability and maintenance support plan is given in Table 4-3.

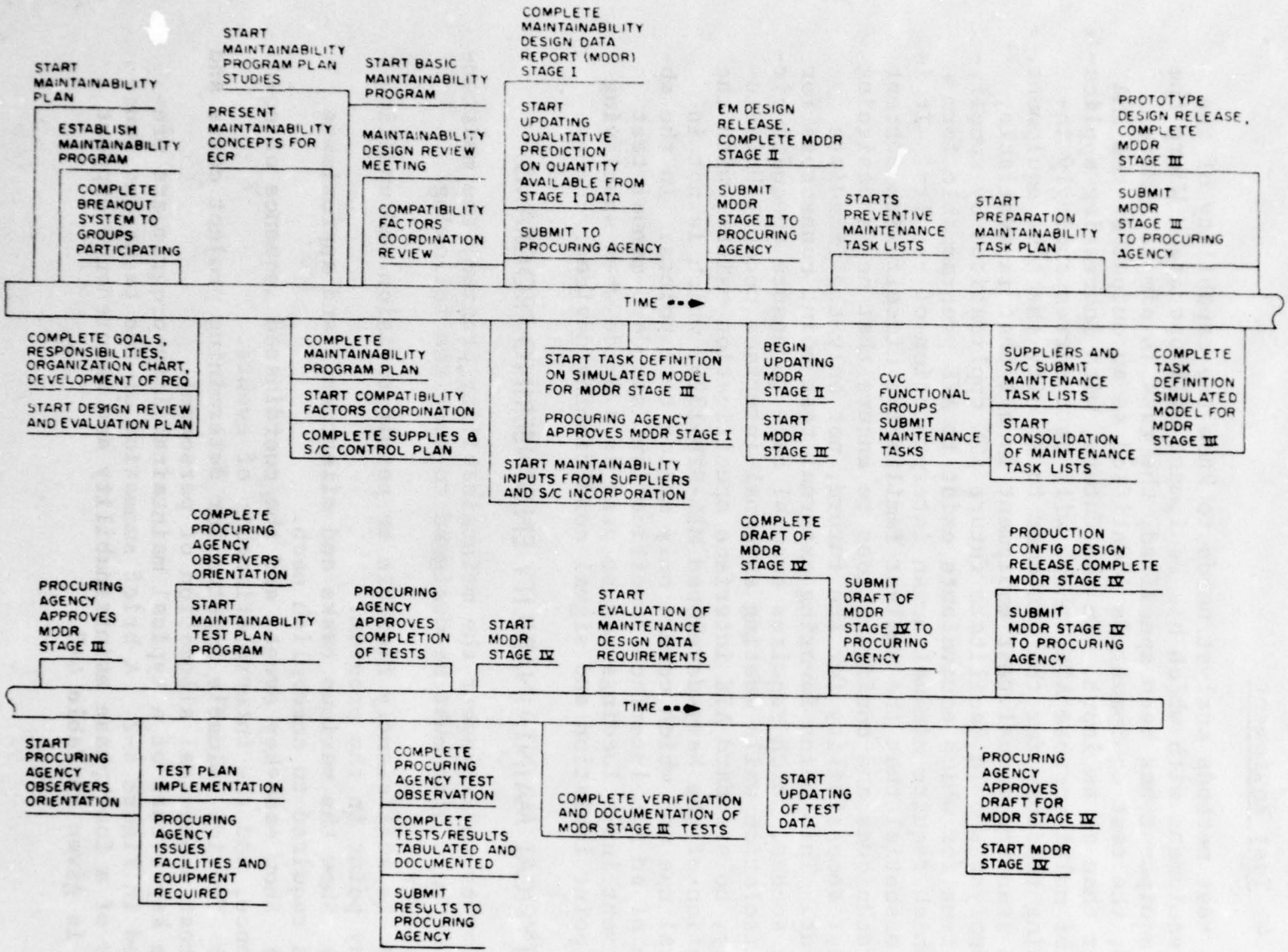


Figure 4-2. Key Events and Task Scheduling of a Typical Maintainability Program (Reference 2)

TABLE 4-3. IMPLEMENTATION OF A MAINTAINABILITY AND MAINTENANCE SUPPORT PROGRAM (Reference 2)

Task or Function	Responsible Activity
Phase I—Concept or Study	
Analyzation by logistics engineering of the type, purpose, function, and utilization of the equipment; qualitative and quantitative maintainability requirements; customer maintenance concepts; organization; and policies. Establish the following maintainability program:	
Define system requirements	System engineering
System concept	System engineering
Analyze maintainability and logistic requirements	Logistics engineering
Preliminary maintenance concept and maintainability guidelines	Logistics engineering
Preliminary maintainability procedures, functions, and goals	Logistics engineering
Preliminary maintenance support procedures and functions	Logistics engineering
Preliminary maintainability and logistics costs	Logistics engineering
Design reviews	System engineering
Trade-offs	System engineering
Revised maintainability data and goals	Logistics engineering
Revised maintenance support data	Logistics engineering
Maintainability and logistics plan	Logistics engineering
Equipment design	Engineering

Task or Function	Responsible Activity
Phase II—Design and Development	
Equipment design	Engineering
Maintainability and logistics plan	Maintainability and logistics
Maintainability functions (updating)	Logistics engineering
Personnel skills and training program	Logistics engineering and training
Support equipment requirements (updating)	Logistics engineering
Shares and documentation program	Supply support
Publications program and implementation	Publications
Government furnished equipment (GFE) design	Logistics engineering
Vendor and/or subcontractor equipment design	Customer
Field support and field engineering plans	Logistics engineering
Maintainability test plan	Logistics engineering
Modification and status	Configuration control

TABLE 4-3. IMPLEMENTATION OF A MAINTAINABILITY AND MAINTENANCE SUPPORT PROGRAM (Continued)

Task or Function	Responsible Activity
Phase III—Production and Test Maintainability equipment reviews conducted by logistics engineering. System, subsystem, and supporting equipment tests include review, evaluation, and validation of the following:	
Prototype production	Manufacturing
Maintainability testing and publications verification program	Maintainability and publications
Maintainability design verification	Maintainability
Design changes and recommendations	Maintainability
Engineering change board	System engineering
Revision of maintainability data	Maintainability
Revision of support equipment	Logistics engineering
Finalization of prototype spares requirements	Supply support

Task or Function	Responsible Activity
Phase IV—Maintainability and Maintenance Reviews Maintainability and maintenance reviews conducted, and a logistic support program implemented during the testing and user phase for the following tasks:	
System test plan	Reliability test and evaluation
Logistic test plan	Logistic support division
Support of system testing	Engineering
Verification of maintainability goals	Maintainability
Verification of logistic support function	Logistic support division
Test report and recommendations	Maintainability
System test summary	Reliability test and evaluation

4-5 THE ATE SELECTION PROCESS

The potential advantages of automatic test equipment (ATE) are well known but the selection of ATE is always a difficult process. Program management approaches must be taken which stress the need for timeliness in making ATE decisions and the best organization of technical and management forces to implement the decision process. The selection of automatic test equipment is properly a part of logistic and maintenance planning; therefore, the following discussion is keyed to the established prime equipment acquisition phases.

Figure 4-3 diagrams the technical, logistic, and management interdisciplinary relationships for the purpose of showing how ATE selection fits in with the overall prime system definition. The first step is a technical definition of the prime equipment to be supported, based on operational mission requirements. This information is needed by logisticians to enable them to develop support concepts, including spares and repair level policies upon which ATE may impinge. The same information enables the test equipment engineer to develop test requirements upon which his ATE recommendations will eventually be based. A double-headed arrow between logistic plans and ATE concept/equipment description denotes the iterative nature of test equipment selection, whereby initial logistic goals may be modified by later evaluation of test equipment capabilities. The prime equipment definition and the logistic plans, which would include ATE recommendations, would then be reviewed by Army Program Management and modified if necessary for compatibility with mission, manning, cost, and schedule requirements. Finally, a combined prime system and support concept would be defined. This same general procedure is followed at every phase of the prime equipment acquisition process, except that the integrated logistic system (ILS) concept and the ATE can be defined in increasing detail as the prime equipment design matures with each subsequent phase. Five phases of prime equipment development are used to determine the various events and decision points of the ATE development cycle. These are:

(1) Conceptual Phase
(2) Validation Phase (Engineering and Development)
(3) Full Scale Development Phase (Operational System Development)
(4) Production Phase
(5) Deployment/Operational Phase (Logistic Support, Inventory Control, Training, etc.)

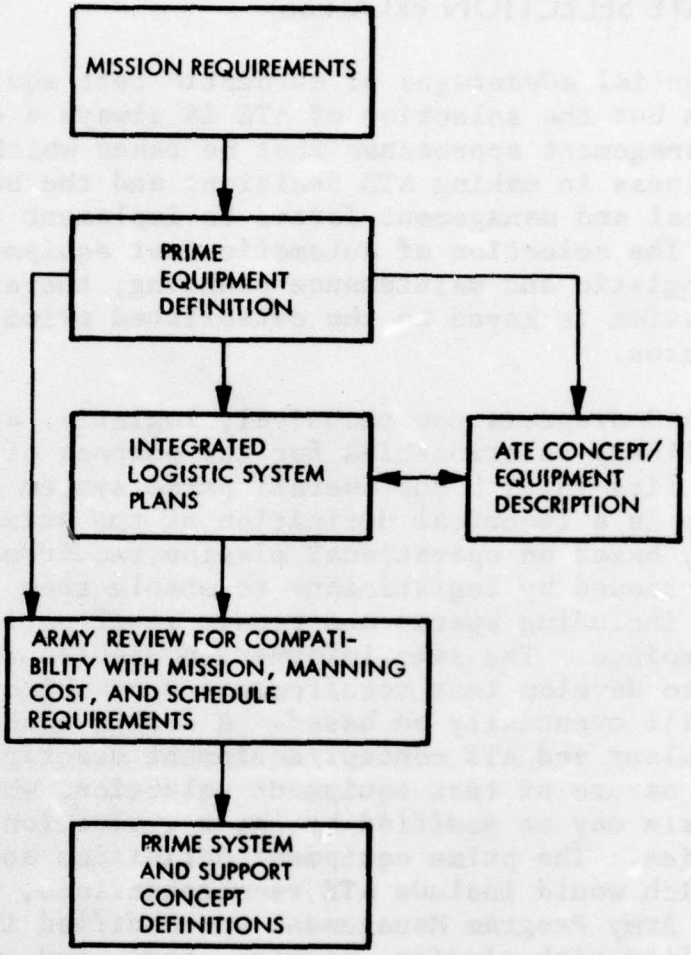


Figure 4-3. Interdisciplinary Relationships of ATE Selection

During the Conceptual Phase, the prime equipment is defined basically by needs and objectives. Very general support requirements are specified, such as desired (or required) operational availability. Comprehensive system studies are performed.

During the Validation Phase, the major program characteristics are validated. This phase ends with the contract to proceed with the detail design. Support alternatives, including off-line versus on-line, are considered and general requirements for support equipment are resolved. Logistic support models which consider system life cycle cost are applicable to this phase.

During the Full Scale Development Phase the prime equipment design is completed, and the support equipment is defined and prototyped.

During the Production Phase off-line test equipment specifications are completed and procurements initiated.

During the Deployment/Operation Phase, prime equipment specifications are generally frozen, and if new test equipment procurements are made, they must be tailored to the existing prime equipment.

4-5.1 IMPACT OF ACQUISITION PHASES

For homogeneous equipment of systems, defined as those in which all components are at a similar stage of development, the ATE/ILS iterative relationship is essentially as shown in Figure 4-4, which is an expansion of the ATE/ILS portion of Figure 4-3. The process starts with the initial proposal of an ILS concept, which will include, among other things, availability, manning budgets, and the repair policy at each maintenance echelon. From these parameters, ATE alternatives toward meeting ILS goals can be defined, and then comparatively evaluated to establish benefit/cost ratios. As a result of this evaluation it may prove necessary to feed changes back into the initial ILS concept, where the ILS concept may have been either too ambitious or not demanding enough. For example, a component tester may be available or producible at a low enough cost to make it economical to change a logistic policy from one which originally called for component repair at depot to a policy of component repair at direct support (DS), with a saving in DS spares and elimination of depot pipeline delays.

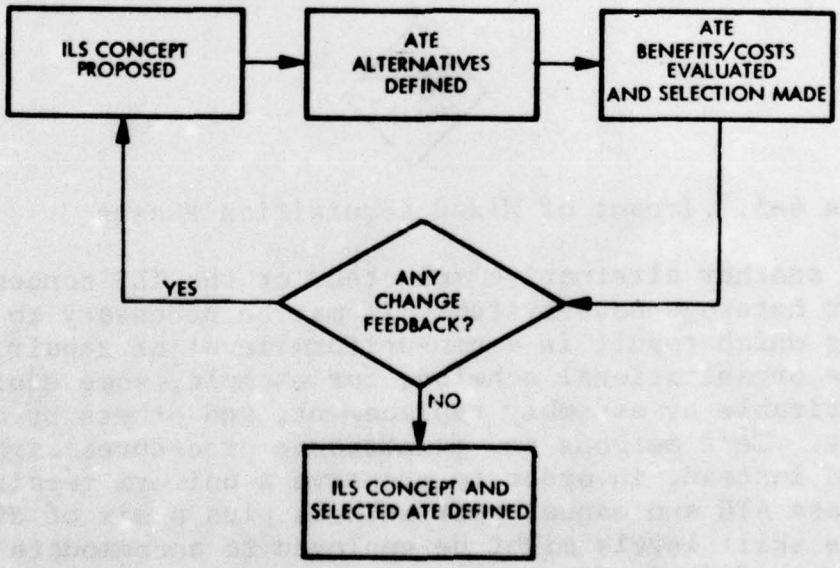


Figure 4-4. Interrelationship of ILS and ATE

For vehicles, aircraft, and other systems which are heterogeneous in that they utilize items in various stages of development, the process shown in Figure 4-4 becomes operative at more than one equipment or indenture level (e.g., equipment, system, component, part, etc.) for each maintenance echelon. Figure 4-5 summarizes the essentials of the test equipment selection process for such a system, consisting of a combination of existing equipment, equipment currently in development, and equipment still in the concept phase. For prime equipment in the first two categories, planned and existing special test equipment must be reviewed for compatibility with the proposed ILS concept. If not compatible, then other test equipment alternatives must be examined,

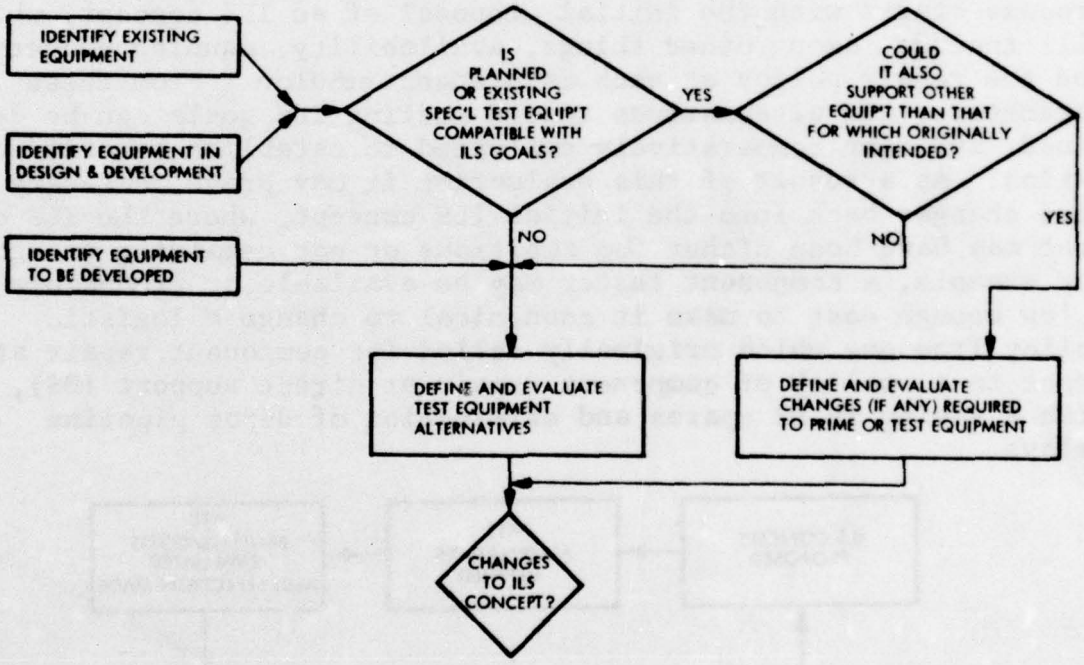


Figure 4-5. Impact of Mixed Acquisition Phases

and either another alternative selected, or the ILS concept altered. For heterogeneous systems, it may be necessary to accept compromises which result in a non-uniform level of repair, so that at the organizational echelon, for example, some equipments may be repairable by assembly replacement, and others by component replacement. Test methods and maintenance procedures might be compromised instead, in order to preserve a uniform repair policy, in which case ATE and manual test methods plus a mix of different maintenance skill levels might be employed to accommodate the required degree of fault diagnosis.

If test equipment originally intended for prime equipment already in existence or in development is compatible with the planned ILS concept, then that same test equipment should be analyzed to determine whether it can also service other equipments in the vehicle, aircraft, or overall prime system, and, if so, whether modifications are required for that purpose. It is obvious that equipment not yet in development affords the Army a full range of ATE options, while for equipment further along, hard choices may be indicated between costly modifications to meet ILS goals, and compromising those goals. Since the available ATE options rapidly diminish as equipment leaves the Validation Phase, it is clear that the maximum benefits of ATE can best be realized through planning which starts with formulation of the program concept. Timeliness is especially critical when planning for built-in or other on-line test equipment configurations which require that anywhere from a portion to all of the test equipment will be an integral part of the prime equipment. Clearly, deferring the decision to use built-in or on-line test until prime equipment design is under way entails the risk of a costly design change.

The selection of off-line test equipment can be deferred to the Production or even to the Development/Operational Phase with the potential risk limited to obtaining less than optimum test performance where the designer has not been required to optimize test point accessibility for use with ATE.

4-5.2 SKILLS REQUIRED FOR ATE SELECTION

The need for ATE decisions to be made early in an acquisition program can only be satisfied by a technical team which contains a mix of prime equipment and ATE skills. The prime system is not normally defined in sufficient detail during the Validation Phase to facilitate ATE selection, except where existing equipment is being used. The team must be capable, then, of synthesizing the proposed system in the detail required to enable test requirements to be analyzed. The ATE part of the team must be experienced enough to apply judgment to fit the inevitable gaps that will appear in the prime equipment test requirements definition during early acquisition phases. Logisticians are needed to ensure that ILS goals are met, and the whole must be under the direction of Army Program Management to maintain program integrity.

4-5.3 PROCEDURE SUMMARY

The ATE selection procedure can be simply summarized in the following steps:

(1) Determine Test Requirements - This step requires knowledge of the prime equipment configuration and its logistic support policies.

(2) Identify ATE Candidates - Locate ATEs in existing inventory (Reference 4) which will meet test requirements. If necessary, postulate new ATE for this purpose.

(3) Evaluate Candidates - Compare candidates on basis of technical performance, logistics, cost, and other predetermined evaluation criteria.

(4) Select the Optimum Candidate - The ATE selected will provide the optimum match to requirements.

4-6 ATE COMPATIBILITY ASSURANCE

This paragraph provides management information for planning and implementing a compatibility assurance program. The return on a well-managed compatibility effort is rewarding. Overall, it means decreased training, decreased mean-time-to-repair, decreased programming, decreased handling, decreased ATE requirements, decreased documentation, decreased storage, decreased interface devices, and a resultant increase in the prime systems effectiveness. The value of these returns over the life cycle of large vehicles or aircraft can easily reach into the thousands of dollars.

Specific guidelines for compatibility assurance can be summarized as follows:

(1) Make compatibility part of the overall integrated logistics support planning.

(2) Perform a detailed compatibility requirements study of support objectives, ATE hardware and software, and all equipment/ATE interfaces.

(3) Include pertinent compatibility requirements in equipment design specifications and ensure compliance by adequate management control.

(4) Avoid vague and ambiguous wording in the specifications and in subsequent correspondence and reports. It is better to omit information than to enter unreliable or misleading data. With automatic equipment, misprints find their way into programs and even a simple error can have undesirable repercussions.

(5) Allocate and schedule sufficient funds to the various compatibility tasks to ensure adequate compatibility design, control, and follow-on activity.

(6) Generate and distribute documentation that clearly outlines compatibility design objectives and methods for achieving them.

(7) Follow up documentation with sufficient orientation and training to ensure a working understanding of compatibility objectives.

(8) Schedule and supervise reviews throughout the design phases to ensure compliance with compatibility requirements. Use qualified, experienced men on the review team.

(9) Consider all items that affect compatibility and be sure that significant factors are not traded off indiscriminately because of electrical or mechanical problems that really are correctable.

(10) Use and refine the compatibility criteria, tradeoff charts, and checklists in this section, as required, to attain compatibility objectives.

4-6.1 BUILDING COMPATIBILITY INTO A PRODUCT

Compatibility can only be built into a product through concerted effort by the designer and management. A satisfactory level of ATE compatibility is achieved by a planned program with specifically defined tasks and objectives. Compatibility starts with the procurement and continues to delivery. It encompasses design considerations, determination of characteristics and performance capabilities, support requirements and test capabilities, logistics and value tradeoffs, human factors, training, and programming. Compatibility is thus a major factor in the overall logistics support planning.

4-6.2 INTEGRATED LOGISTICS SUPPORT

The increased complexity of military systems and contemporary operational concepts have forced a recognition that a system does not consist of equipment alone. This recognition has caused the development of a system management discipline by the military called Integrated Logistics Support (ILS). ATE compatibility design is one element of ILS planning which directly and indirectly affects all the elements of life cycle costs. ILS relates to the analysis and implementation of many system elements which have come to include computer programs, training, maintenance, facilities, procedures, instrumentation, data reduction, and transportation, in addition to prime mission equipment factors. ATE and ATE-compatible equipments will have significant impact on the economics and performance of future Army materiel, provided the proper balance between compatibility and performance is achieved in the design process.

The objectives of compatibility design are inherent in the military's philosophy of Integrated Logistics Support (ILS). Effective compatibility design will be a major contribution to ILS goals. ILS is, in effect, the formulation and implementation of an overall engineering plan for the support of prime systems

(Reference 5). Emphasis is placed on early integration of the support aspects when systems are in the conceptual stage and when systems engineering tradeoffs can affect designs before hardware commitments are made. The ILS elements related to support have recently been summarized by the office of the Secretary of Defense as Maintainability and Reliability, Maintenance Planning, Support and Test Equipment, Supply, Support, Personnel and Training, Transportation and Handling, Technical Data, Facilities, Management Data, and Funding. An objective of ILS is to emphasize these elements in the decision-making process while, at the same time, economically providing a high degree of readiness.

Design engineers will be called upon more frequently to incorporate these techniques which permit the system to meet all design requirements yet reduce ownership cost during system life. The trend in the military is to consider total package (or life cycle) costs in many future procurements. A demand, therefore, exists for key management and design personnel who are knowledgeable of, and sympathetic with, the associated systems engineering disciplines.

Table 4-4 summarizes many of the effects of maintenance and logistics factors on equipment design. Note the parallelism to ATE compatibility design objectives. Since over 25 percent of the defense budget is spent on supporting systems in the field, consideration of these factors is a justifiable ILS objective.

In line with the objectives of future logistic support, the Department of Defense has prepared the Integrated Logistics Support Planning Guide. (Defense Documentation Center, AD663456.) The guide outlines concepts and objectives that call for management actions integrating all support elements in order to maximize the availability of equipment and to minimize support costs. Intended for use in ILS planning, the procedures of the guide are designed to reduce costly changes to production hardware or expensive modification of operational equipment.

This is illustrated in Figure 4-6 (an excerpt from the guide) which represents ILS as the early integration of system support aspects with the prime system and equipment design. This is followed by a continuing planned support program effectively interfacing with the prime equipment throughout the life cycle.

Ideally, the logistics support effort is initiated in the concept phase and a controlled program is carried out for the concept, definition, development, production, and operational phases.

TABLE 4-4. MAINTENANCE AND LOGISTIC EFFECTS ON DESIGN

Design or Logistic Factor	ILS Requirement or Significance
Built-in Test	Inadequacy may cause mission failure due to undetected equipment faults
BIT Fault Isolation Level	Affects the cost of replacement assemblies and support equipment
Maintenance Personnel Training	Consider simplification of support tasks in equipment design
Technical Data and Documentation	Complexity of design increases operations and maintenance documentation costs
Reliability and Maintainability	Perform design tradeoffs on a life cycle cost basis to set the proper balance
Repair Level Decisions	Consider effect of maintenance hierarchy and repair level on life cycle costs
Test Equipment (manual, special-purpose or general-purpose automatic)	Consider effect of maintenance workload on choice and location of test equipment and personnel requirements
Management Data	Organize management data to simplify incorporation of modifications to fielded equipment
Funding	Consider support aspects in funding for design engineering
Equipment Packaging	Consider support aspects in addition to reliability, accessibility, heat transfer, etc., in packaging design and the relation to repair level decisions

The ultimate objective is to provide a high degree of readiness at reasonable cost.

4-6.3 COMPATIBILITY OBJECTIVES

Compatibility objectives must reflect the support concept and the intended support equipment. They should be within the current state-of-design art and follow good design practice.

Compatibility objectives are ATE objectives, that is, to alleviate support problems created by the increasing role of complex equipments and to decrease life cycle costs. The application of an automated test system to mechanical, hydraulic and pneumatic equipment support accomplishes this mission in a number of ways:

(1) By a reduction in test time of four (or more) -to-one with a commensurate decrease in test equipment, manpower, and the facilities that support them

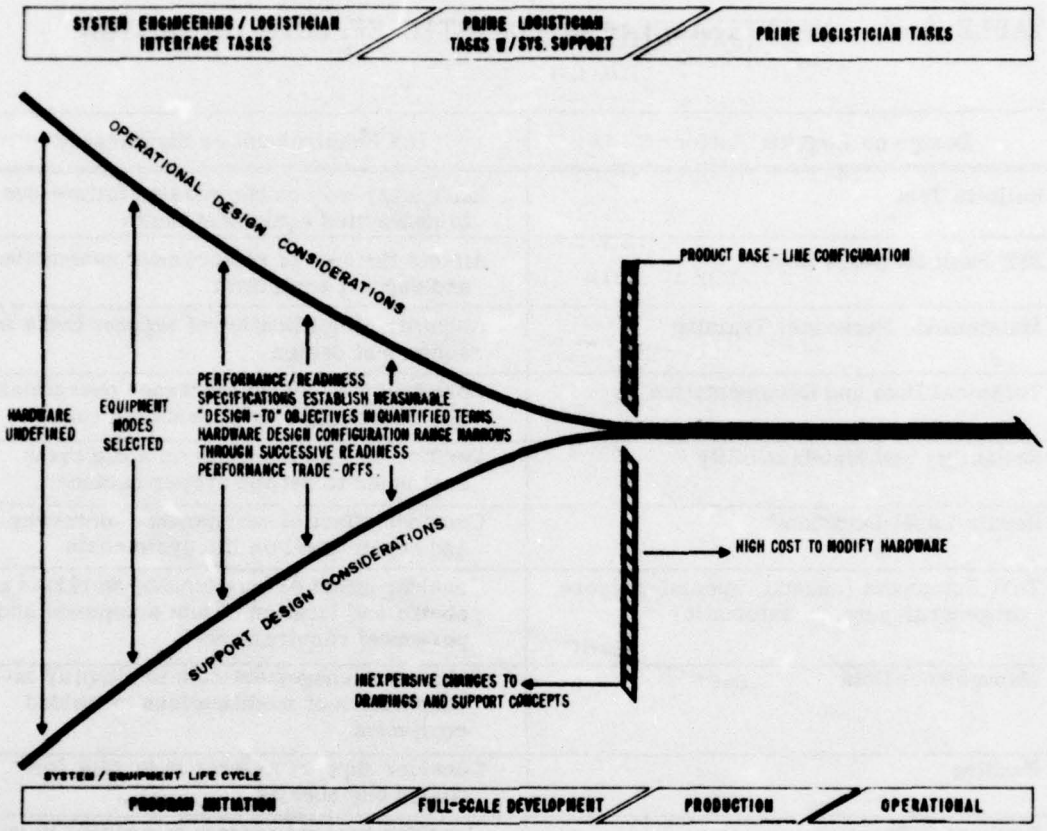


Figure 4-6. Support Impact on System Design

(2) By improved standardization of testing and test results, since all test instructions are pre-recorded and performed automatically in the same sequence for each component tested and since test results may be automatically recorded

(3) By a reduction in operator skill level and training requirements due to use of pre-recorded test instructions, standardization of test procedures and test results

(4) By a reduction in requirements for new test equipment, since introduction of new prime systems into the military inventory requires new test program sets rather than new test equipments

(5) By a reduction in calibration time and calibration equipments required, since the support system generally contains internal standards for self-test and calibration checks.

4-6.4 DESIGNING FOR COMPATIBILITY OBJECTIVES

The equipment designer can ensure ATE compatibility objectives by following three simple rules:

(1) Know Your ATE. Develop a working familiarity with applicable ATE capabilities and operating characteristics so that testing requirements are developed that are inherently compatible.

(2) Modularize Design. Functionally group components at a replaceable level which minimizes the test points needed to fully evaluate operational performance and isolate faults on the ATE.

(3) Provide Test Points. Allocate test points at each replacement level and bring them out to an accessible connector. Clearly and completely define the GO/NO-GO criteria for each test point.

4-6.5 THE COST OF COMPATIBILITY

Attainment of a high compatibility goal requires time and effort. Nevertheless, good design practice and manufacturing control can all result in substantial savings in terms of overall development costs because problems typically encountered in integration, performance evaluation, and test programming are minimized.

Prior to the formulation of any proposal in response to an RFQ, compatibility requirements must be fully understood. This can not be overemphasized. The contractor must thoroughly evaluate the requirements and work statement, and consult with the procuring agency if further clarification is necessary. Not only should the compatibility requirements be fully understood, but the procedures to be used to monitor and acceptance test the compatibility aspects of the design should also be understood. Naturally, cost is a function of the requirements and the proficiency of the proposer to meet them.

4-6.6 THE PROCUREMENT - CONTRACT SPECIFICATIONS

Contract Specifications are a vital communications link between customer and contractor. These specifications must succinctly reflect all of the ATE compatibility requirements. The method of procurement, the degree to which the contract documents reflect customer needs, and the realism of these requirements will vitally affect the inherent and operational compatibility of the equipment to be tested with the ATE. The customer must tell the contractor exactly what is wanted and what constitutes acceptable proof of compliance to the requirements set forth. The customer must also select a contractor who can meet these requirements.

Terms like "as a design goal" and "maximum compatibility consistent with state-of-the-art" should be avoided in ATE compatible equipment procurement specifications. These terms are subject to broad interpretation that will vary considerably among contractors

and do not offer a firm basis for evaluation of contractor performance.

It is necessary to establish definite requirements for compatibility with the ATE at the onset. This is best accomplished by citing, in all specification and procurement documents, a reference to one central specification that defines general requirements for compatibility. (For airborne electronic equipment intended for installation in Naval aircraft, that specification is AR-8, Reference 6). A document similar to AR-8, addressed to mechanical, hydraulic and pneumatic ATE has yet to be written by the Army.

Documents such as AR-8 should not and can not specify precise methods and techniques for achieving complete compatibility. To do so would almost certainly lead to premature obsolescence in view of today's rapidly changing technology, and might also unnecessarily restrict the creativity of equipment designers. For this reason, more specific requirements may be necessary to augment the general requirements. This is virtually a necessity in the development of a complete integrated vehicle system since such systems are not often the product of a single vendor. In effect, the prime contractor must publish definitive task statements delineating specific methods for the design of compatible equipment. For example, the prime contractor on a vehicle development program should specify standard test connectors for all replaceable components and use standardized pin assignments (where applicable) for each test function. When the prime contractor issues amendments to the original specifications, care should be taken to avoid any wording that might be construed as reducing the basic compatibility requirements.

Vague wording in contract specifications and task statements will create problems in bidding and bid evaluation. In fact, vagaries may jeopardize a bidder's chance of winning the contract award; worse yet, the contract may go to the bidder who is less qualified or who did not fully consider the problem.

4-6.7 REPORTING, MONITORING, AND ACCEPTANCE

Whether they be for compatibility or any other performance characteristic, equipment requirements should be specified with tolerance limits wherever possible. In development, these requirements are design objectives. They may have to be changed by the time development is completed, either as a result of the state-of-the-art considerations, ATE capabilities, cost, weight, value,

or other tradeoffs. However, these specified tolerance limits to requirements are most important in order to obtain a meaningful tradeoff analysis when design goals cannot be achieved. Furthermore, they provide a baseline from which to monitor progress and, hence, results become more standardized and reporting, monitoring, and acceptance more meaningful.

4-6.7.1 Reporting

All contracts require progress reporting in one form or another. With ATE, compatibility design performance is generally reported in the form of a compatibility report. The compatibility report must show what provisions are being made to ensure that the designed component is suitable for testing by the ATE and that these provisions for its maintenance are compatible with the stated support concepts. On the basis of this analysis, the Army may decide to proceed with the development or to adjust certain requirements in order to meet the required compatibility. The purpose of this analysis is to provide the information needed to assess the risk related to the total specification requirements. Before proceeding into production, there should be agreement between the Army and the contractor that the final specification and requirements have a high probability of achieving stated support objectives.

4-6.7.2 Monitoring

Every task in a compatibility program must be monitored to assure timely and adequate completion. This monitoring is a key function of engineering and project management. In addition to informal conversations, design reviews should be scheduled at critical points in the design process. First, during the proposal stage where the vendor describes how he will meet compatibility requirements in terms of block diagrams depicting functionally modularized and replaceable assemblies and components, testing levels, maintenance objectives, and compatibility design controls. Second, during the concept stage where design reviews are conducted to evaluate the design concept and plan. Development of a preliminary compatibility report should have progressed to the detailed functional block diagram level. The compatibility report enables periodic compatibility predictions or estimates. Accomplishments can be verified by actual testing as soon as the engineering prototype or service test models are available. Third, at a preliminary design review where drawings, parts, and engineering data are evaluated. Here, the compatibility report has progressed to the test-point test-parameter definition stage of development and compatibility analyses are discussed during

the design review. Fourth, at a prototype design review which follows the same procedure as the previous design review. However, in addition to the normal agenda, there may be inputs on maintainability, reliability, and test program design. The compatibility report has progressed to a final stage of refinement reflecting the more detailed inputs of test design and failure analysis. A fifth and final design review may be held to digest inputs from integration, environmental, and acceptance testing. The final design review may also include a value review where every detail of the design is subjected to a cost/compatibility tradeoff. In this final review, tradeoffs should be done on a life cycle cost basis.

4-6.7.3 Acceptance

From the point of view of specification and contract, "acceptance" is the periodic evaluation inspection, and test that determines whether a satisfactory level of ATE compatibility has been achieved. Compatibility verification should be given the same priority as other design acceptance tests. Thus, for all practical purposes, design for compatibility will be an integral part of the overall design with the achievement and verification of this characteristic on a par with achievement of basic performance requirements.

In order to comply with specification requirements for compatibility design performance, the contractor must have the organization and personnel to cope with all the facets of design evaluation and testing. Facilities must be available to adequately determine and verify performance and fault isolation test parameters in a "systems operational environment" (i.e., the test requirements, performance limits, tolerances, accuracy of measurement, and confidence levels required of effective equipment operation).

The customer must clearly define the level of ATE compatibility required (test time, isolation level, replacement level, testing confidence, interface limits, etc.) so that test and evaluation results will render valid conclusions and avoid problems that otherwise will be detected only too late, when test program sets are developed and made operational.

Vague requirements for compatibility lead to broad interpretation by designers and reviewers. These same vague or incomplete requirements also lead to untenable responses to proposal requests and ambiguous situations and problems in negotiation with the contracting officer.

4-6.8 PROOF OF COMPLIANCE

Proof of compliance consists of delivering all the compatibility reports, test results, and review and evaluation reports that were generated to demonstrate ATE compatibility. In proof of compliance, there is no attempt to further consider the adequacy of this data. It is entirely an action to show compliance with contract requirements and provides a data base from which the customer can adjust future specification and contract requirements for improved compatibility performance.

In many cases, the equipment will be deployed to a location not equipped with automatic support equipment. However, since the support equipment may be furnished at some later date, compatibility requirements may be imposed in anticipation of this event. There is a natural tendency in this situation to de-emphasize the importance of the compatibility report and other documents. This information, however, is of vital importance to successful development of test programs when the automated support equipment does become available and test program sets are procured. For this reason, all reports and data must be complete and technically adequate.

4-6.9 ORGANIZATIONAL APPROACH

The customer expects an efficient project management to achieve design objectives. An integral part of project management is the compatibility function. Contractors will find it necessary to establish, depending on the size of the procurement, a compatibility organization to assist design engineers with the knowledge and techniques of compatibility reports, to participate in design reviews, and to promote overall system effectiveness.

Only recently, the one requirement most design engineers were primarily concerned with was that of meeting the requirements of the equipment operating specification. It was left to the test program designer to resolve any and all test problems. These problems gave rise to the need for more exact measures of compatibility which are just now being formulated. Compatibility has produced a need for specialists trained in hardware design, test programming, and ATE compatibility requirements, who can assist in the design function.

4-6.10 FOLLOW-UP

One important aspect of any project is feedback of support system effectiveness data (the integrated operating effectiveness of

ATE, the equipment and supporting software) from the using activity. This data is valuable to customer and contractor, both in their relations and in the development of improved compatibility performance for future procurements. In addition to user follow-up and feedback from customer to contractor, there is also the desirability of feedback to subcontractors.

In the total picture, follow-up and performance surveillance can be used to pinpoint problems not only in equipment design, but also in the test programs, the ATE installation, maintenance and preventive maintenance procedures; personnel deficiencies; inadequacies in instruction manuals; and, most important, inadequacies in the original specification of compatibility design requirements.

4-6.11 IMPACT OF MAINTENANCE PHILOSOPHY ON COMPATIBILITY

Planned use for an avionics equipment, with its established support policies, procedures, level and degree of maintenance, establishes another set of compatibility boundaries for the contractor. The customer should provide the contractor with quantitative information on the degree of isolation required, the spares concept, repair policy, and throwaway criteria for the level of maintenance to be applied to the equipment, at the depot, or at other support facilities.

While recognizing that maintenance criteria will vary for different weapons systems, it is better to have an established maintenance plan and let a contractor take a waiver, than to have no plan at all.

4-6.12 IMPACT OF LOGISTICS SUPPORT ON COMPATIBILITY

In order to effect optimal compatibility design, the contractor must be acquainted with the customer's logistic support philosophy. The ease of maintenance considerations dictated by automatic support procedures will lead a contractor to lean heavily on the use of non-repairable expendable parts and components in his design. However, there are logistic factors that may alter the expendability of the component, resulting in a requirement for repair at the depot or possibly even at the site. Factors suggesting a possible change in repair policy are:

(1) The skill of maintenance personnel at the operating levels
(2) The cost of supporting spare components
(3) Available storage space
(4) The number of times a component is used

(5) The requirement for special test equipment, procedures, or interconnection devices
(6) The allowable maintenance times.
The contractor should get a definite policy from the customer prior to beginning detailed equipment design.

4-6.13 MANAGEMENT PROCEDURES FOR COMPATIBILITY ASSURANCE

ATE compatibility design is both a management and a technical problem. In managing a compatibility assurance program to achieve the desired optimum system effectiveness, emphasis must be placed on five major program steps:
(1) Defining compatibility program goals and the means for implementing them
(2) Obtaining adequate funds for the program
(3) Establishing specific requirements for design, reporting, and acceptance
(4) Establishing tradeoff relationships between ATE compatibility and other system parameters
(5) Formulating compatibility measures and evaluating the results.

4-6.13.1 Developing a Compatibility Program

There are two aspects in developing an effective compatibility program for a specific project:
(1) Establishing standards of performance and specifying the tasks required to implement them
(2) Measuring the performance for each task, evaluating it in relationship to the established standards, and effecting corrective actions.
Individual tasks should be decided upon and separate controls established for each of these tasks. In general, the following steps should be taken:
(1) Define the Compatibility Objective in Specific Terms - From the viewpoint of defining objectives, to say "ATE compatible" or "economically repairable" is meaningless and does not give the subcontractor or the designer adequate direction or bounds. A quantitative definition for each compatibility objective is necessary; e.g.:
   (a) A component shall contain one or more uniquely identifiable functions.
   (b) A test point or test points shall be provided to evaluate the operational GO/NO-GO performance of each function.
   (c) Test points shall be brought out on standard intersystem connectors.

(d) Components with a cost/reliability ratio of 0.01 dollar/hour or less shall be classified as throw-away items, and so forth.

An analysis may be required to initially define some of the program objectives. If the specific requirements prove to be unreasonable, they should be adjusted as the program matures.

(2) Define Program Requirements - The requirement for compatibility reports must be delineated and the number of interim reports must be specified. The degree of detail required in each report, the number of compatibility design reviews, and the criteria for report acceptance and control must also be specified.

(3) Establish Responsibility - Responsibility for each program requirement must be established and assigned to a single group or individual. This serves to formalize the program and provides greater impetus toward achieving desired results.

(4) Define Other Organizational Structure - Achievement of a compatible design demands the cooperation of all segments of the organizations involved. It is important that liaison between organizations be defined along with the individuals responsible for ensuring that liaison is accomplished.

(5) Provide Adequate Funding - Compatibility design by itself is simply good design practice and should not require additional funds. The preparation, analysis, and action on compatibility reports, however, does require additional funding. Estimating funding requirements, once the compatibility test responsibilities have been defined, will be relatively easy. Funds provided for compatibility assurance are an investment that will pay off in terms of lower total program costs.

(6) Prepare Written Procedures - Well-written procedures ensure understanding of task responsibilities. They provide program control which can be effectively referenced and can be updated as original plans give way to experienced results.

(7) Establish Schedules - There is an optimal time when each step in a development program takes place relative to the overall project effort. Concept reviews should be compatible with system designs, interim reviews compatible with subsystem and component designs, etc. The completion of tasks must be scheduled with enough lead time to effectively correct design problems.

(8) Training - A program is of little value if the people involved do not understand its objectives nor how to go about making them a reality. A good training program will make all levels of personnel aware of their role in compatibility and provide them with the knowledge required to successfully complete their tasks.

4-6.13.2 Scope of Compatibility Program

A program to assure ATE compatibility must actually start in the proposal phase and continue throughout design and development, manufacturing, test, field evaluation, and service use. Although it is often too late to consider compatibility after the development stage, much can be learned throughout the life of the contract. Compatibility data properly gathered, digested, and applied to future programs can add significantly to their effectiveness. The data can also be used as an aid in product changes to improve the effectiveness of the current system. Criteria applicable to the scope of a compatibility program are listed in Table 4-5. These criteria highlight the disciplines required to assure an ATE compatible design.

4-6.13.3 Requirements Study

Compatibility requirements for mechanical, hydraulic and pneumatic materiel must be consistent with overall system support requirements and must be realistic. These compatibility requirements provide an input for subcontract specifications regarding replaceable components and also provide an input to individual contractor design teams. Requirements will vary as a function of current Integrated Logistics Support (ILS) policy. Hence, the first step in establishing requirements is to become familiar with ILS objectives.

Talent to be applied to this effort includes systems engineers versed on Automatic Test application, ILS, and equipment design. Initial requirement analysis is accomplished during the proposal period and should include a preliminary design that is sufficiently detailed so the approximate number of components and test points, and the spectrum of stimulus and measurement parameters, can be established. Performing the initial analysis during the proposal stage not only helps to assure ATE compatibility, but also places the contractor in a better competitive position.

The end result of the requirements study will be quantitative statements of the degree of compatibility for different classes of equipment and materiel in terms of:

(a) Operational performance
(b) Fault isolation level
(c) Repair criteria
(d) Throwaway criteria
(e) Special test criteria
(f) Tradeoff criteria.

TABLE 4-5. A COMPATIBILITY PROGRAM CHECK LIST

The plan recognizes:

(a) The importance of compatible design.

(b) The necessity for an organized approach.

(c) That compatibility is inherent in the design.

(d) Improvements are best accomplished in early stages of concept and design.

(e) ATE compatible design decreases test programming.

(f) ATE compatible design decreases the need for complex interfaces and special test equipment.

(g) ATE compatible design decreases life cycle costs.

(h) Awareness of what others are doing serves to improve and standardize design.

(i) Goals need to be quantitatively stated.

(j) That logistic and operational environments reflect on compatibility requirements.

(k) That the basis for each tradeoff needs to be stated.

(l) That the steps taken to arrive at the objective are progressive and capable of management analysis and control.

The organization:

(a) Has an important position within overall management.
(b) Has the authority to establish and implement policy.
(c) Implements control through assigned authority and responsibility.
(d) Clearly defines authority and responsibility.
(e) Time phases activities for optimal response.
(f) Develops effective measures of progress.

The implementation:

(a) Encompasses prime contractors and subcontractors alike.

(b) Is time phased to ensure compatibility qualification before initial production.

(c) Is realistic, timely, and revised as necessary.

(d) Includes advanced studies necessary to resolve problem designs.

(e) Provides organization, facilities, and procedures for monitoring and evaluating compatibility progress.

(f) Facilitates corrective action.

(g) Includes courses to raise skills and make personnel compatibility conscious.

(h) Provides organization, facilities, and procedures for documenting compatibility policy and standards.

(i) Provides organization, facilities, and procedures for collecting and disseminating design guidance.

(j) Monitors specifications (performance, environmental, reliability, etc.) to ensure consistency with compatibility objectives.

4-6.14 THE COMPATIBILITY DESIGN REVIEW

Design reviews detect potential problem areas with regard to such items as performance, producibility, reliability, and maintainability. These reviews, held during the course of the project, assure that product design is in accordance with contractual requirements and that it conforms to sound engineering practices. When the contract requires the product to be supported by ATE, the review must also assure that the design embodies the essentials of ATE compatibility.

Because ATE compatibility is still a new design discipline, three and possibly four design reviews are recommended. In addition, the review of a proposal can serve as a pre-contractual compatibility review. The four in-process reviews are conducted at the concept, preliminary design, prototype design, and final design stages of equipment development.

The concept review should be held early in the project before any great amount of engineering work. Basic premises of compatibility design set forth by requirements studies must be investigated. Preliminary review should be held when schematics are approximately 90 percent complete. Prototype review should be held during prototype equipment testing, and final review should be held prior to production release. Final review represents the last opportunity to effect changes to achieve compatibility objectives without considerable schedule and cost problems. It also affords the opportunity to evaluate the results of earlier recommendations. During the final period, attention is concentrated upon specific performance and fault isolation measurements. Very likely the test program design is in process and provides a meaningful evaluation of such items as ATE system interactions, dynamic test requirements, programming implementation, tolerance considerations, and maintainability features.

All reviews should be performed systematically, with specific objectives at each step in the design process. Check lists and forms should be used which question and/or establish the existence of the more important compatibility design parameters; the partitioning of functions, the addition of test points, human factors, details of packaging, and maintainability.

Particular attention should be focused on the man-machine relationship. Too frequently, the human factors aspect, both from the viewpoint of operability and maintainability, has a low priority. With ATE, human factors take on a greater significance.

Maintenance personnel no longer have the opportunity to live with every operating detail and idiosyncrasy of the component equipment. The ATE does the thinking for them, and, if the operator is asked to adapt to the results of a marginal test, an intermittent result, a difficult adjustment, or a function not tested, very likely he will be poorly equipped to effectively handle it.

Design reviews should be conducted by experienced people. The staff to handle this work should include representatives from each of the following organizations: maintainability engineering, design engineering, test program design, and systems and support engineering. Human engineering specialists and field-service engineers also contribute to a good design review team. With proper training and updating on state-of-the-art design concepts, the maintainability engineer or specialist could be responsible for the review of ATE compatibility.

4-6.14.1 Functions of the Design Review Team

It is the responsibility of the compatibility design review team to be cognizant of both mechanical and electrical aspects of equipment design and of contractual responsibilities in the areas of performance, maintainability, and compatibility. Review participants, as a whole, must be thoroughly familiar with the ATE and its capabilities and limitations, and must be capable of recommendations for optimum application to the equipment support requirement.

The vehicle or aircraft prime contractor, in particular, is responsible for the operational performance of the equipment supported by the ATE. To guarantee mission performance, experienced consultants may be used to help evaluate maintainability features of the equipment and its support.

The prime equipment designer is responsible for developing a test plan and implementing it into his design in the form of replaceable modules with meaningful test points and measurable parameters.

The ATE test program designer is responsible for implementing the test plan into a programmed test procedure. He must scrutinize the test plan for completeness, approach, logic, and sequence. Based on past experience, he must be able to flag trouble spots or known problems and to suggest alternate approaches.

The maintainability engineer is responsible for blending maintainability, accessibility and compatibility factors with other factors (weight, reliability, cost, etc.) in some optimum proportion. He knows there are many possible mixes and optimization must be with respect to many constraints.

Overall objectives of the review team, then, are the careful tradeoff of all constraints, one against the other, to achieve optimum systems effectiveness.

4-6.14.2 Requirements for an Effective Review Program

An effective review program requires: an established design review group; written procedures delineating the scheduling, reporting, and responsibilities for design reviews; and written design guidelines which tell how to design ATE compatible equipment. General duties of the compatibility design review chairman and his staff are summarized in Table 4-6.

4-6.15 FUNDING A COMPATIBILITY DESIGN ASSURANCE PROGRAM

Funds for a compatibility program must be appropriated in the overall project budget. Thus, a decision must be made as to the division of funds between compatibility assurance and all other activities associated with the project. A detailed listing of the funding elements in a thorough compatibility program follows:

(1) Compatibility requirement studies.

(2) Development and implementation of a compatibility program plan encompassing:

- (a) The plan itself
- (b) Instructions
- (c) Training
- (d) Policy
- (e) Coordination with ILS
- (f) Allocation of responsibility
- (g) Compatibility standards
- (h) Tradeoff criteria
- (i) Measurement criteria
- (j) Control of subcontractors and vendors
- (k) Testing the adequacy of compatibility provisions
- (l) Acceptance testing
- (m) Design reviews
- (n) Status reporting
- (o) Compatibility problem analysis and feedback, updating, instructions, training, policy, etc.
- (p) Field follow-up
- (q) Final report.

TABLE 4-6. GENERAL RESPONSIBILITIES OF DESIGN REVIEW TEAM MEMBERS

Duties of the Chairman

(a) Schedule meetings, establish agenda, prepare and distribute material and assignments pertinent to the design review.

(b) Conduct the design review meeting.

(c) Prepare and distribute minutes of the design review meeting and maintain a permanent file of the minutes.

(d) Prepare reports for responsible management and other concerned personnel as necessary.

(e) Negotiate with the various organizations to resolve any differences that arise. Refer irreconcilable problems to the chief engineer and/or program manager.

(f) Notify program management of any changes that have impact on the statement of work, price, delivery, or in any way affect the customer.

(g) Assign corrective action to members of the design review team, and maintain a corrective action log.

(h) Follow corrective action assignments to completion.

(i) Prepare finalized results of design review meetings and submit to appropriate management.

(j) Maintain and disseminate changes to compatibility design policy and guidelines.

Duties of Members

(a) Review the design and related documents to determine problem areas and prepare the necessary inputs for the design review meeting.

(b) Participate in the design review meetings scheduled by the chairman.

(c) Expedite completion of corrective action assignments resulting from the design review meeting.

(d) Submit reports to chairman when corrective action assignments are completed.

(3) Continuous monitoring of the design during the entire project.
(4) Training
(5) Preparation of compatibility reports
(6) Design reviews
(7) Prototype equipment testing

The cost of a compatibility program can be justified by potential savings in numerous areas; for example:

(1) Integration and test (e.g., failure investigation and correction)
(2) Decreased ATE interface complexity
(3) Less specialized test equipment
(4) Increased reliability resulting from less handling
(5) Improved maintainability
(6) More components supported by each ATE
(7) Decreased test programming costs
(8) Less operator training.

The quantitative savings fall in the range between 10 to 30 percent of the costs typically experienced in the integration, programming, and service support of a vehicle or aircraft system.

4-7 TEST POINT SELECTION

Test points for mechanical, hydraulic and pneumatic equipment may be functional related or electrical-transducer related. Functional related test points are actually provisions in the equipment to determine operating condition or component/system function. A good example of this kind of test point are the standard capped tees and parts in hydraulic and pneumatic equipment provided for pressure measurement. These are access points to the hydraulic or pneumatic circuits which can be used to troubleshoot system/vehicle operational faults. When the pressure gauge inserted into the part has an electrical interface (i.e., the pressure reading may be digitized and sent on wires to a standard test connector) it is considered to be of the electrical-transducer related variety. Of course, the electrical interface can be built into the vehicle or can be attached to the vehicle only when preventive maintenance or troubleshooting/fault diagnosis is performed. Selection of test points is an integral procedure of achieving ATE compatibility. By way of review, there are five basic steps for achieving ATE compatibility in the design of mechanical, hydraulic and pneumatic equipment:

(1) Define the basic equipment requirements in terms of overall ATE compatibility.
(2) Analyze the specific requirements for system and component performance testing and incorporate these requirements in the detailed design specifications.

(3) Analyze the specific requirements for subsystem and component diagnostic fault isolation and incorporate these requirements in the detailed design specifications.

(4) Establish a quality assurance program to ensure that the compatibility design specifications are being interpreted and implemented properly.

(5) Provide sufficient documentation in the necessary form to assist in test program design, operation/maintenance manuals, logistics, and other support functions.

Test points should be provided on all vehicles for all levels of maintenance; the test points must be compatible with the test equipment designated or selected for deployment use. By selecting and connecting test points in an optimum fashion, it is possible in many instances to use the same functional test points and connectors (if electrical) to satisfy organizational maintenance requirements, as well as the requirements of direct support, general support and depot maintenance. Test point requirements for all levels of maintenance are summarized in generalized form in Table 4-7.

TABLE 4-7. TEST POINT REQUIREMENTS CHART

A. Functional Test Point Selection: Test points shall provide safe and convenient access to hydraulic, pneumatic, and electrical circuits and mechanical functions for:

1. Determination or verification of the existence of a fault or performance degradation.
2. Localization of the fault to the degree needed for efficient repair.
3. Checkout of the equipment to ascertain that the fault or degradation has been corrected.

B. Functional Test Point Arrangement: Electrical test points shall be exposed and grouped in a single multi-pin connector which is readily accessible at the level of maintenance for which it is intended. All external test point connectors shall be provided with captive caps. The test points shall be grouped by maintenance levels as follows:

1. Equipment test points for Organizational Maintenance
2. Fault location test points for Organizational Maintenance
3. Component test points for Direct and General Support Maintenance
4. Component repair test points for Direct and General Support Maintenance.

TABLE 4-7. TEST POINT REQUIREMENTS CHART (Continued)

Electrical test points (1) and (2) should, if connector size permits, be combined in one connector. Electrical test points (1), (2), and (3) shall be brought to the surface of the assembly. Electrical test points (4) need not be brought to the surface of the assembly.

C. Organizational and Direct Support Maintenance Test Points:

Equipment Test Points. Equipment Test Points shall be provided to ascertain whether the equipment is satisfactorily performing the function for which it was designed, while the equipment is installed in the vehicle or aircraft. They should provide the means for:

1. Introducing any functional inputs and/or loads to the subsystem for performance of an overall or "end-to-end" quantitative check.
2. Measuring overall or "end-to-end" performance parameters which will enable a quantitative readout regarding the functional performance of the equipment.
3. Obviating the need for disconnecting operational cables during test.

Fault Location Test Points. Fault Location Test Points are required to facilitate repair or periodic check of the BIT (Built-In Test) circuitry and to ascertain which component contains the fault. Unless size prohibits, these test points should be grouped in the same connector with the subsystem test points. They should provide the means for:

1. Introducing any functional inputs and/or dummy loads to the subsystem necessary for the performance of a periodic check, malfunction, isolation, and/or subsystem calibration check
2. Measuring the necessary input/output parameters to enable unambiguous isolation of any and all faulty components of the subsystem.
3. Measurement of necessary input/output parameters to enable calibration or alignment of the components while installed in the vehicle as a system.
4. Obviating the need for disconnecting operational cables during test.

TABLE 4-7. TEST POINT REQUIREMENTS CHART (Continued)

D. General Support and Depot Maintenance Test Points:

Component Test Points. Component Test Points are required in each system to quantitatively determine the performance level of the system and, in the event of a failure, to ascertain which component contained therein is at fault. They should, when used in conjunction with operational connector access, provide the means for:

1. Performance of an overall or "end-to-end" quantitative check
2. Measuring the necessary input/output parameters to enable isolation of any and all faulty components of the system.
3. Measurement of necessary input/output parameters to enable calibration or alignment of the system.
4. Introducing any other necessary functional inputs and/or dummy loads necessary for bench test.
5. Enable isolation to a single component in 90 percent of the cases of probable malfunction of that component isolation to groups of two components or less in 95 percent of the cases, and isolation of three components or less in all cases.

4-8 ATE TEST PROGRAM DESIGN

Efficient design of automatic test programs for complex equipments is dependent on five major factors:

(1) Good source material on the equipment to be tested.
(2) Familiarity with the ATE and test objectives.
(3) Technical competence.
(4) The ability to identify and resolve problem areas.
(5) Attention to detail.

Of equal importance is recognition that test designs validated must also meet performance requirements under actual service conditions.

The following paragraphs discuss the above factors and outline a systematic approach that will assist in program design. Potential and latent problems are also discussed.

4-8.1 BASIC TEST DESIGN PROCESS

Figure 4-7 illustrates a basic test design process which has proven effective for a number of ATE systems. Modifications to this process can be and have been made, on occasion, to suit particular software requirements and schedules. Differences are primarily in the degree of management control, task responsibility, and work-flow mechanization. In any event, an efficient test design process should include, but not be limited to, the following:

(1) A test requirements analysis and test plan.
(2) At least one concept review.
(3) Detailed design of the test program and associated interface.
(4) At least one design review before production and validation of the program set.

In brief, the test designer is responsible for studying all of the source documentation and guidelines, and preparing a test plan for conceptual review by a seasoned management-engineering team. Upon approval of the plan, the test designer proceeds with the detailed test program and interface design, including generation of an English Language Procedure (ELP). The ELP is then subjected to a final design review, at which time the test program is then subjected to a final design review, at which time the test program is sampled and scrutinized for integrity and conformance to test objectives and specifications. The program is then released for production and the interface for fabrication.

Details of each step in the basic test design process are given in the following paragraphs.

4-8.1.1 Test Requirements Analysis (TRA)

The prime function of the TRA is to have the test designer analyze existing documentation and identify any incompatibilities between the equipment performance requirements and ATE capabilities. The test designer must also identify fault isolation levels and procedures, and contemplated problems or side effects. Once these areas have been investigated, the test designer can formulate a basic design approach and make trade-offs as required. The feasibility of going ahead with a detailed test plan can then be evaluated. Prototype testing is not recommended as part of the TRA.

During the TRA, the test designer must establish criteria for specifying GO/NO-GO limits in the test design. These limits must be consistent with the level of performance necessary to meet the

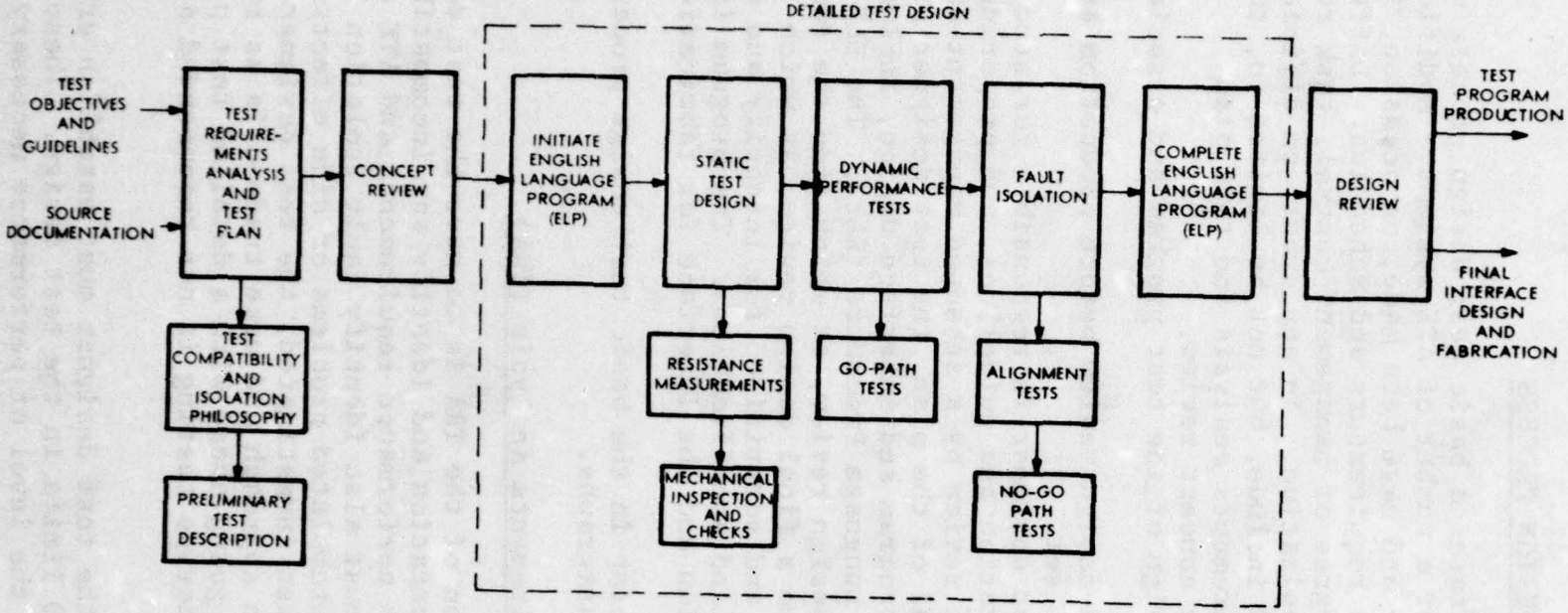


Figure 4-7. Basic Test Design Process for Equipment Test Programs and for ATE Self-Test Programs.

needs of the ultimate user. If test program limits are based, for example, on acceptance test procedures that are unnecessarily tight, many serviceable units may be rejected. Similarly, limits that are too broad may not prove effective under specified service conditions, or may even result in intermittent operation.

The following procedure is a recommended approach to the TRA task:

(1) Collect a data package consisting of equipment performance specifications, technical manuals, schematics, drawings, test procedures, and any other related source material applicable to test design of that equipment.

(2) Study the data package for familiarity with basic equipment operation, physical characteristics, and maintainability.

(3) Establish the relationship between the component/subsystem to be tested and the rest of the system in which it is used.

(4) Identify ATE equipment interface requirements and establish minimum requirements for electrical connections and grounding.

(5) Analyze in detail the topology, test point access, and signal flow within the equipment. Identify all transfer functions, interfaces, and isolation levels. If necessary, obtain engineering design data which answers such questions as:

(a) What function does this particular flow or action fulfill in the prime equipment?

(b) What characteristics of this flow or action are essential for prime equipment performance?

(c) What effect would an undetected variation from specified performance have on the prime equipment?

Answers to these questions are necessary for effective cost-performance trade-offs when a required test cannot be exactly duplicated or simulated with the ATE.

(6) List signal parameters which cannot be measured to the required accuracy with the standard complement of ATE measurement devices. Identify stimulus requirements which are not available from the ATE or which are not within required accuracy.

Based on the foregoing information, the test designer should perform an engineering evaluation and make a list of recommendations for the disposition of requirements not covered in the Design Policy Manual or beyond the capabilities of the ATE. Possible alternatives include:

(1) Development of a special test technique using existing ATE hardware and/or software.

(2) Adding a new capability to the ATE itself, which may require hardware redesign or addition of a new subassembly or test feature.

(3) Use of manual or semi-automatic test procedures, as opposed to a fully automatic approach.

(4) Modification of the basic test requirement or maintenance objective.

4-8.1.2 Test Plan Preparation

The test plan documents the results of the TRA in a format adaptable to review by a concept review team. It indicates all test requirements and deviations from established design policy, and recommends disposition of problem items. Depending on equipment complexity and ATE compatibility, the test plan may be a simple report, flow chart, or tabular listing, or a comprehensive design document. Oral presentations and outlines are not considered satisfactory substitutes for test plans, unless the test design is a near-duplicate of a previous one.

For purpose of standardization, and as a basis for later design documentation, a specification for preparing test plans should be written and published in a Design Policy Manual approved by the contracting agency.

Contents of a test plan should include the following:

(1) A list of applicable source information, including revision letters and dates.

(2) A step-by-step breakdown of the proposed test design in terms of performance testing of the equipment functions in accordance with component test specifications. Where possible, group the tests into functional categories, with the higher probability of failure first in sequence. Every functional test contemplated in the performance test sequence (GO-path) should stipulate exact stimulus requirements and measurement parameters and accuracies. Prototype testing of the equipment during test plan preparation is recommended only for situations where supporting documentation is incomplete or inconsistent, or when the test designer feels it is important to confirm or investigate circuit characteristics, alternate test techniques, and other factors not considered fully during the Test Requirements Analysis.

(3) An indication of fault isolation tests to be executed in the event that equipment performance requirements are not met. The extent of fault analysis at this time is a function of the complexity of the equipment. The main purpose is to establish alignment and fault isolation policy and procedures, rather than to describe troubleshooting details down to a specific faulty part.

(4) A preliminary ATE equipment interconnection diagram emphasizing interface requirements, particularly signal transducer equipment. Requirements for special tools, fixtures, or test facilities should be noted (e.g., the requirement for purging or cleaning).

(5) A list of problem areas and recommended action, wherever possible, based on sound engineering judgment and realistic schedules. It is not recommended that mathematical models actually be constructed for cost-effectiveness trade-off studies, since technical assistance and guidance from the concept review team may obviate that approach.

(6) Engineering notes of special interest, including calculations required to substantiate testing problems and alternate solutions.

The language in the test plan should be the same as that used in a normal engineering report, so as to facilitate review by both engineering and non-engineering type personnel. If test-oriented programming languages are available which fit this category, their application may prove worthwhile. The intent here is conceptual design, devoid for the most part of the mechanics associated with the ATE coding structure.

When a large number of test programs are being prepared simultaneously or within a close time frame, the use of an information retrieval index (library of approved test methods) is worthwhile to minimize redundancy of design effort. On many projects involving similar types of components, the same design approach or technique is often applicable, either directly or with minor modification. By furnishing a list of approved approaches or techniques, the amount of research could be minimized or new avenues of thought introduced. The index could also list the names of key personnel to contact, by ATE/equipment category.

4-8.1.3 Concept Review

The primary function of the concept review is to evaluate the proposed test plan and to provide direction, as required, to ensure compatibility with support requirements and to minimize implementation costs. A secondary, but also important, function is to consider the impact of the test approach on documentation, spares, training, and other maintainability requirements.

For major equipment or assembly programs, the concept review team should include an ATE systems engineer (a specialist in ATE application), a senior test program designer (a specialist in test techniques), a prime equipment systems engineer (a specialist in the operating requirements of the equipment familiar with the support requirements), and a representative from quality assurance to chair the review. Representatives from the project management office, the contracting agency, and other personnel may participate as required. Each reviewer should have specific areas of

responsibility. The review chairman should be responsible for documenting and following up on action items.

For component test programs, a smaller number of reviewers may prove adequate, but the scope of the review must not be reduced.

Copies of the test plan should be available to the reviewers prior to the meeting. This will enable reviewers to study the test plan in detail, so that they can gather material necessary to resolve indicated problem areas. At least one copy of all source documentation must be available at the meeting.

Suggested responsibilities of the different reviewers are listed below:

(1) The ATE systems engineer should be responsible for compatibility between the test plan and the ATE hardware, and should be in a position to assess special requirements, time constraints, and system capabilities not specifically covered in ATE system and assembly specifications. In many ATE systems, for example, certain stimuli and measurement assemblies have inherent capabilities beyond those actually specified. The ATE systems engineer should be aware of system applications beyond the specified capability, and should be able to make recommendations thereto. Similarly, some measurement specifications make allowances in accuracy for long-term drift, but neglect short-term inaccuracies, resolution, deviation, etc. If short-term inaccuracy or repeatability is not specified, the test program may not be able to compensate for zero offsets and linearity errors. Here again, the ATE systems engineer should be in a position to provide or gather the necessary information.

(2) The senior test program designer should be the most critical member of the concept review team. It is his responsibility to scrutinize the entire test plan in terms of overall coverage, test approach and logic, and test sequence. Based on past experience, he should be able to flag trouble spots or known problems and to suggest alternate approaches. Special software and testing techniques should be introduced, whenever applicable, to ensure optimum test design. Interface design and fabrication, and their relationship to other test programs, should also be analyzed, especially if one interface adapter is to support a number of test programs. Attention should also be given to possible problems that might arise during the production and validation phases.

(3) The prime equipment systems engineer (or user representative) has responsibility for performance of the equipment supported by the ATE. He should check the test plan for compatibility with prime equipment performance, maintenance, and logistics requirements under service conditions. The test plan must check all

equipment performance characteristics necessary to guarantee mission success.

If the prime equipment is no longer in a developmental phase and has been deployed for field use, it may be advantageous to have a maintenance officer or someone else familiar with the prime equipment in attendance at the concept review.

(4) The quality assurance representative is the logical review chairman and should also be responsible for analyzing the test plan for conformance with the Design Policy Manual (Reference 7) and contractual requirements, primarily in the areas of reliability, accessibility, maintainability, and compatibility between the proposed test procedure, the proposed interface, and previous test programs. He should be cognizant of both mechanical and electrical problems inherent in supporting the equipment and should record all decisions conditional to test design go-ahead. He should also be prepared to discuss calibration and alignment procedure, packaging and mounting of special components within the interface adapter, accessibility of test points, recommended replacement procedures, and so forth. Of all the review members, this man should be most sensitive to overall quality and the needs of ATE test station operators and repair technicians.

(5) The project management office (PMO) representative will be called in to review and resolve problems of compliance with contractual requirements and commitments. He is also responsible for resolution of anticipated cost and scheduling problems, and action follow-on. Since the efficiency of the test design process may be dependent on close cooperation between different contractors in pursuit of a common objective, he should be prepared to promote harmony and to furnish liaison during this critical concept phase.

(6) Representatives of the contracting agency provide an important link between contractor and user, and are responsible for the ultimate success of each test program. They should review the test plan in detail and become familiar with all aspects of the proposed design. Vague points should be explored and clarified, and areas overlooked by others should be challenged. They should be prepared to assess technical and contractual problems arising during the concept review and to make suggestions, wherever possible. Firm commitments and acknowledgements made at the concept review will set precedence for the rest of the test program design process.

4-9 ATE TEST PROGRAM QUALITY ASSURANCE

Test programming for ATE can be a well-defined, orderly, and predictable process, conducive to close management control.

Development of a successful automatic test system is enhanced by timely application of proven management procedures such as quality assurance plans, design reviews, change control procedures, and other controls over cost, schedule, production, and end-item configuration.

Test programming management is most difficult when there is a division of responsibility between independent contractors. In this case, responsibility for application of strong management controls must necessarily fall on the agency which controls development funding. This agency is naturally accustomed to dealing with the various organizations and has the necessary contractual leverage to enforce compliance and to resolve any disputes over individual responsibilities.

The paragraphs which follow are devoted to a general discussion of management procedures which are applicable to assuring quality in automatic test programs.

4-9.1 ROLE OF QUALITY CONTROL IN THE OVERALL PROCESS

Quality is a product characteristic which can be designed into a test program by means of deliberate control efforts in all phases of conception, design, production, validation, and field usage. A satisfactory level of quality can be achieved only by a planned effort with specific defined tasks and objectives. The role of quality control is to establish a plan that assures compliance with requirements of the contract. A good quality program plan will detect promptly and correct design practices which could result in defective program tests. Technical data, design policy, or other elements of contract performance which could create system support problems must be identified and changed as the result of the quality program plan. Personnel performing the quality functions should have sufficiently well-defined responsibility, authority, and organizational stature to: identify and act on quality problems, maintain design policy current, and to accumulate all the necessary design review results, inspection reports, quality conformance data, and shipping dates as evidence of meeting contractual requirements.

4-9.2 QUALITY PROGRAM PLAN

The development of a Quality Program Plan is the first step in the quality assurance process. It is a general description of the tasks required to assure that the procured software will satisfy the support requirements of the prime equipment and the ATE.

It indicates the planning, organization, direction, and control necessary to carry out each task. An optimal plan will make maximum use of the techniques and procedures discussed in this section and will be kept current by revisions, supplements, and bulletins, as necessary, throughout the life of the project.

Quality Program Plans should include, as a minimum, a synopsis and task description. The synopsis presents the test-design objectives and the overall quality control approach. Included in the synopsis are techniques which will be employed to exercise close control over that program quality including the organizational structure, and the quality flow diagram (Figure 4-8) with data inputs, outputs, and quality control actions at the appropriate monitoring points.

The task descriptions present documentation, manning, procedure, and other pertinent factors relating to each function and will provide guidance to personnel in their efforts to support the control plan. Table 4-8 is an outline list of recommended quality program tasks. Some of the key tasks are described in greater detail in subsequent paragraphs.

4-9.2.1 Design Policy Manual

The Design Policy Manual (Reference 7) will provide a basic guide for test program design relative to a specific ATE application. It should be generated by test design personnel with inputs from project management, standards, documentation, and human engineering. A procedure must be established for control of the Design Policy Manual which alerts all concerned as to any proposed changes and assures distribution of all approved changes.

As a minimum, the manual should cover the following policy items:

(1) Level of fault isolation as dictated by the contract. In determining the level of isolation, the following points should be considered:

- (a) The level of support at which the test program will be used.
- (b) The spares philosophy for the prime equipment.
- (c) The cost-effectiveness of the level of isolation. It is less costly to isolate faults to the next level of replacement than to isolate to a lower level within a single program. However, consideration should be given to the cost of additional test programs required if the ultimate isolation must be to a lower level of replacement.

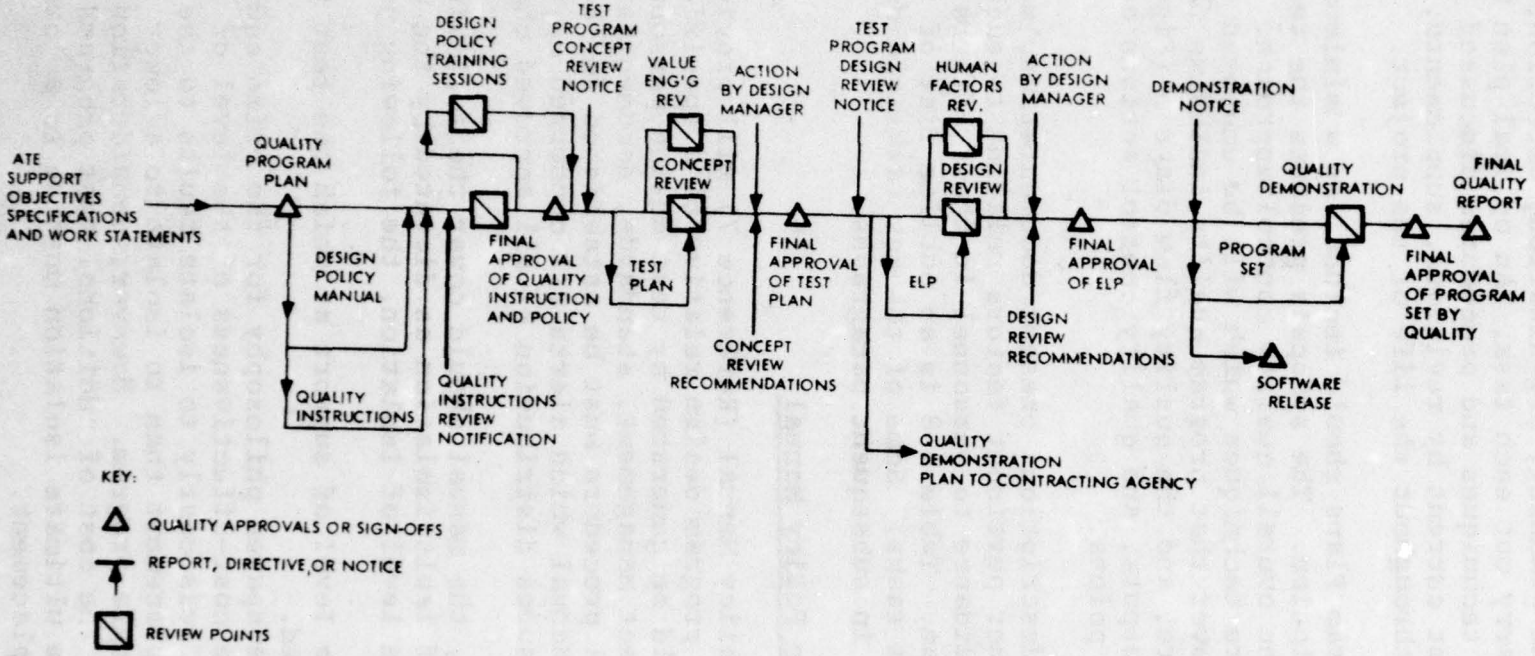


Figure 4-8. Typical Quality Flow Chart (Test Software Design and Validation Phase)

TABLE 4-8. QUALITY PROGRAM OUTLINE

QUALITY PROGRAM PLAN	The quality program plan provides effective requirements and procedures for implementing a quality program.
DESIGN POLICY MANUAL	The design policy manual establishes design standards, preferred test techniques, and general design considerations oriented toward the supported system.
QUALITY INSTRUCTIONS	Quality instructions are detailed instructions covering all tasks described in the Quality Program Plan and constitute quality requirements imposed on applicable design, production, quality, and configuration-control groups for their particular efforts.
QUALITY TRAINING	Quality training provides indoctrination in the basic objectives of the quality program and the efforts that must be exerted to reach the specified quality standards.
VALUE ENGINEERING	Value engineering promotes cost-effective solutions to software design trade-offs consistent with logistics and support objectives.
RELIABILITY AND FAILURE MODE PREDICTIONS	Reliability and failure mode predictions provide guidance to designers and quality personnel in developing and evaluating test program logic.
CONCEPT REVIEW	The concept review provides a qualitative design review of the test plan to assure a uniform design approach consistent with conventional design practices and the application of optimum and standard techniques.

TABLE 4-8. QUALITY PROGRAM OUTLINE (Continued)

DESIGN REVIEW	The design review provides a qualitative review of the completed ELP and a quantitative design review of the fault-isolation logic.
PRODUCTION PROCEDURES	The production procedures ensure against loss of data, destruction of magnetic tape, library files, and unnecessary computer runs during the production and validation phases.
QUALITY DEMONSTRATION PLAN	The quality demonstration plan provides statistical and procedural means of demonstrating program set quality at the time of software release.
FAILURE REPORTING, ANALYSIS, AND FEEDBACK SYSTEM	Failure reporting, analysis, and feedback provide data to correct program set deficiencies identified by shakedown in an operational environment.
HUMAN FACTORS ENGINEERING	Human factors engineering analyzes the man-machine interface associated with software items to evaluate critical manual procedures involved in fault location and repair.
DISTRIBUTION PLAN	The distribution plan provides logistic control guidelines and defines procedures required to support all ATE using activities with program sets.
CONFIGURATION CONTROL PLAN	The configuration control plan describes the steps and responsibilities to prepare and process design changes, and ensures system integrity.
QUALITY REPORT	The quality report provides a summation of quality effort throughout test program generation as evidence of meeting contractural requirements.

(2) The level of confidence required of the program and method of determination. The higher the level of confidence, the greater the effort required for test design and validation.

(3) The source language to be used in the english language test program (ELP). This should be by reference to a specific support-software users manual and/or the programming manual for the ATE on which the programs will be run.

(4) ELP format and content. This should be in the form of an ELP "boiler plate" with instructions for completion.

(5) Standard components and parts and restrictions for adaptive hardware. The restrictions should cover component types, total power dissipation, and sharing of adaptive devices.

(6) Limit considerations including method of determination, minimum accuracy ratio, and resolution of conflicts.

(7) Standard message formats to be used for communication with the operator.

(8) Preferred test techniques cataloged and indexed. This should also cover the philosophy for testing adjustable or calibrated parameters, redundant circuits, self-test or BITE circuitry, and equipment controls and indicators.

(9) Preferred test sequence and the use of ATE and interface adapter performance tests.

(10) ATE capability by reference to a performance specification.

(11) The numbering system to be employed for identification of tests in automatic programs.

(12) The definition of failures which constitute a legal fault.

(13) Maintenance objectives. This should cover policy on testing speed, probing, repair and priority on accuracy/speed/fault isolation trade-offs.

4-9.2.2 Generate Quality Instructions

Quality Instructions should be produced by a quality assurance group and must be compatible with the Design Policy Manual. This document shall detail:

(1) Level and format for all review documentation and records relative to each step in the Quality Program Plan.

(2) The procedure to be employed in scheduling the quality control activities.

(3) The method of resolving conflicts with respect to test program goals, test techniques, and documentation.

(4) Methods for instituting quality program plan changes.

(5) The responsibilties and duties of each participator in design reviews and demonstrations.

4-9.2.3 Implement A Quality Training Program

A quality training program should be implemented prior to initiation of test program design. The training session for test designer, QA and other personnel should be aimed at familiarization with the various aspects of the quality plan, interpretation of the Design Policy Manual and Quality Instructions, the use of other services to enhance quality, and procedures for resolution of conflicts affecting the quality of test programs, interface adapters, and documentation.

All personnel should attend a training session prior to participation in any effort related to the quality Program Plan. If there is a major policy change which affects the quality plan, a special training session should be called to detail the affect of the change.

4-9.2.4 Design Review Criteria

Design reviews provide a critical analysis of proposed engineering designs to assure that the delivered product will meet contractual specifications, and conform to reliable design practices. General factors to be considered in a design review include performance, reliability, maintainability, producibility, schedule, cost, safety, and value. The design review also helps to assure a uniform design approach, consistency with conventional design practices, and the application of optimum or standard techniques, whenever possible. Three types of design reviews are recommended for test program design: test plan concept review, ELP design review, and supplemental reviews.

4-9.2.4.1 Conceptual Design Review - The conceptual design review is qualitative in nature. It is held soon after the design effort begins upon completion of the overall test approach (test plan). This review is held to ensure that the test design approach conforms to contractual requirements and to ensure that the requirements themselves are consistent with user maintenance objectives. The conceptual design review will emphasize completeness and soundness of the test design approach with respect to system and functional requirements, ATE capability, design specifications, costs, and schedules. It presents an opportunity to review the basic test plan, and to request specification changes and waivers for unrealizable requirements.

Any recommended deviations from guidelines established by the Design Policy Manual should be recorded and approved. Recorded data should include:

(1) The projected program development schedule, as required to enable compatible scheduling of QA tasks. Future design reviews on a particular equipment to be tested should not be delayed due to poor scheduling of QA efforts.
(2) The equipment performance characteristics which QA will use during the final design review and at demonstration to verify compliance with program goals.
(3) The level of isolation agreed upon. This enables QA to evaluate the final design for isolation to the proper level and for identification of all items by proper nomenclature.
(4) A list of items to be excluded from isolation. This will prevent invalid program evaluation.
(5) The confidence factor to be attained by the test program. This sets the scores required during final design review and demonstration.
(6) A list of legal failure modes to guide fault selection for design review and demonstration.
(7) The minimum acceptable accuracy ratio. This will enable a check of test limits for assurance that deviations are properly approved.
(8) A list of action items.
(9) Approved copy of the Test Plan.
(10) Sign-off sheet.

4-9.2.4.2 Design Review - The design review is conducted at the completion of test program design. It is held on each equipment to be tested when the ELP is complete, but prior to release for coding and interface fabrication. Emphasis will be placed on optimum test design, compliance with customer requirements and standard techniques, and also on such factors as safety, environment, human factors, and value engineering.

The quality of the program logic is tested at this review by identifying fault symptoms and requiring the test designer to show how the program logic detects and identifies the failure. A specific score should be attained prior to approval of the test program design.

Prior to the scheduled design review of a test program, the QA activity should ensure that the following tasks are performed:
(1) A review package is issued to all reviewers including:
    (a) A copy of the concept review record and the results of all action items.
    (b) A copy of the ELP.
    (c) An equipment documentation package.

(2) Reviewers must become familiar with the ELP and equipment performance characteristics, and the physical make-up of the equipment, its components and parts.

(3) A list of faults is generated and failure symptoms are listed. Selection is based on component type, quantity, and historical failure data for these items.

(4) An approval sheet is prepared for use during the design review which includes entries for the following:

(a) ELP format and compatibility acceptability.
(b) Human factors and value (man-machine interface quality and standardization) acceptability.
(c) Graphical display and/or documentation acceptability.
(d) Interface adapter/transducer requirements acceptability.
(e) Specific faults to be simulated and resultant score.
(f) Remarks relative to program peculiar items (deviations from design policy).
(g) Accepted deviations from Test Plan.
(h) Action items.
(i) Sign-off block.

4-9.2.4.3 Supplemental Design Reviews - Supplemental design reviews may be held to coordinate the different activities, approve design revisions, or review validation failures. Engineering supervision may request a supplemental design review at any phase of the project for resolving unique problems including changes to scope of work.

4-9.2.5 Production Procedures

Production procedures for developmental test programs must provide a means of maintaining a file of the current versions of all test programs, establish controls for updating these programs, and create a method for controlling the number of updates. The type and degree of procedure required is a function of the safety and controls built into the support system and the cost of operating the system.

Production procedures for deliverable programs must, in addition, provide protection for the master, verification of the data on all copies, and inspection of the physical characteristics, packing, and shipping.

4-9.2.6 Quality Demonstration Plan

The quality demonstration plan is a test and inspection procedure for demonstrating program set quality. It is prepared by the contractor, and submitted to and approved by the contracting

agency prior to starting demonstration testing. In general, the plan specifies the criteria and conditions for determining acceptance or rejection. Specifically, it should cover the following five areas: (1) quality requirements, (2) testing and inspection procedures, (3) conditions and responsibilities, (4) test definitions, (5) test and inspection reporting.

4-9.2.7 Failure Reporting System

No matter how well a test program is checked out during validation, some operational problems will be experienced when the program set is distributed for general use. The most common problems will be: equipment failure modes which are not correctly isolated; operator errors caused by misinterpretation of instructions; and excessive false alarm rates caused by tight decision limits and by unanticipated noise and transients. The feedback of information obtained from the analysis of these failures is one of the principal mechanisms for improving a test system.

Field failure data collection has four primary purposes:
(1) To measure the achieved operational quality level.
(2) To provide data for current product improvement efforts.
(3) To provide customer visibility and management control.
(4) To update test design policy to minimize similar problems in new designs.

Failure data are recorded, reported, and controlled in many ways -- from the controlled approach where personnel are specifically assigned to record all occurrences in a refined, accurate, and detailed way, to an uncontrolled approach where operators are relied upon to record failure events in logs and to forward copies to central collection points on a routine basis.

An important part of any failure reporting system is the requirement for serialization of certain items in order to provide an effective means of identification for reliability control. In general, each program library tape (PLT)* should have a serial number assigned. Operator's technical manuals (TM) should be identified by the operator and some means of printing or recording the actual measured values is desirable. Most ATE systems include a printer for measured values. This data should be attached to the failure report form to aid in problem analysis.

A comprehensive failure analysis and corrective action feedback loop must determine:

*Library of individual equipment test program tapes on a single reel.

(1) What failed.
(2) How it failed.
(3) Why it failed.

Failure data provides information to determine the first two factors. The third item which is essential to corrective action, may be identified by an alert operator, but usually requires analysis and verification on the part of the investigator.

4-9.2.8 Configuration Control Plan

A coordinated configuration control plan is required to ensure that each of the various test installations is supplied and sustained with a compatible set of test programs and interface accessories necessary for performance of the assigned maintenance support mission. Each supplier of hardware and software is required to maintain, through configuration control, detailed records of all QA accepted program sets. These records normally include serial numbers, copy numbers, revision letters, and shipping dates for all items.

Configuration control, in addition to control records, should maintain reproducible copies of listings, tapes, and technical manuals for all versions of accepted test programs. These reproducible copies are necessary for production of replacements for any items accidentally lost or damaged by test program users. Standard data processing techniques can be used to store and maintain these historical data files. Listings and tapes can then be reproduced from data files stored on magnetic tapes.

4-9.2.9 Change Control

Change control is a normal part of the overall configuration control plan. At completion of validation, a formal change control procedure must be imposed. This change control serves many purposes. The first and most important is to ensure that everyone affected by a change is promptly notified through engineering change notices. A second purpose is to ensure that all changes are reviewed and approved by a competent change review board. This will serve to minimize costly, unnecessary changes and will identify any changes that exceed a contractual scope of work. Changes which exceed scope of work require approval by the contracting officer of the agency which is procuring the automatic test programs. These changes are submitted as Engineering Change Proposals.

Change control can be imposed at almost any point in the software design process. Informal change control, however, is very

effective and does not slow the process as long as total responsibility is held by a single close-knit group within an organization. Even with a simple organizational structure, a formal change control procedure becomes necessary when any items such as data for technical manuals or interface requirements are released to other groups within the organization (such as drafting, technical writing, mechanical design, and production).

In a more complex organizational structure where responsibility for the performance of the end item is shared by more than one contractor (or even by more than one independent group within a single organization), a formal change control procedure must be imposed at the point where responsibility changes hands.

The test program user or contracting agency should be represented on change control boards when several contractors are involved. User representation is also desirable when changes become necessary after initial deployment of the test program sets.

4-9.2.10 Program Set Distribution Plan

The distribution of program sets or kits (tapes, interface/transducer accessories, and operating documentation) must be closely controlled to assure that each ATE installation is supplied and sustained with a complete and current complement of program sets and spares to support its mission. Outdated items must be appropriately destroyed, correctly updated if it is other than a tape, or returned to the distribution point for appropriate action. This is best handled by a central agency. Initial request by a test facility for program sets should be made by specifying the system (or systems) to be maintained and the revision status of each item in the system. The distributing agency can then select (preferably by data processing means) the required program sets and update agency deployment records listing using facilities for each program. It is from these lists that program set modifications are issued. When a program set is modified, all facilities using the particular program will be issued the modified item, items, or item conversion instructions. The facility should acknowledge receipt of each item, return obsolete items if repairable, and submit certification of destruction of nonrepairable items, as directed.

Requests for replacement items should include the equipment or component identification number and reason for request (item destroyed, lost, etc.). Special forms should be prepared to appropriately control and process request data.

In some ATE applications, the time lag through the user's normal supply channels is much too long to keep up with rapidly changing deployment patterns of the prime equipments which are supported by the ATE. One solution to this problem is to bypass conventional supply channels and authorize users to procure test program sets directly from the test programming organization. This procedure imposes an additional responsibility on test program configuration control personnel. In this case, it will be necessary to keep up-to-date records of the particular equipment configuration at each user installation. This data is necessary to ensure that test programs supplied to each installation are compatible with the ATE configuration and with the mix of prime equipments supported by that installation. After acceptance of a test program set, a final quality report should be transmitted to the contracting agency. This report should properly identify the program set and contain the complete or appropriate portions of the following properly signed documents which contain all test records and design policy waivers:

(1) A concept review record.
(2) Design review record.
(3) Configuration baseline record.
(4) Demonstration record.

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CHAPTER 5
REVIEWS AND TRADE-OFFS

SECTION I

IN-PROCESS REVIEWS

5-1 GENERAL

Army policy applicable to the materiel acquisition process is outlined in AR 1000-1. Among the expanded policies listed in AR 71-9 is the policy:

> "initiate acquisition, threat, logistics, training, test and evaluation considerations throughout the life cycle."

Concerns for logistics, training, test and evaluation extend from the conceptual phase through full-scale production and deployment.

5-2 THE ACQUISITION PROCESS

During the conceptual phase, the combat developer examines threat projections and forecasts to determine capabilities, doctrine, or materiel that will improve the Army forces. Critical logistics support issues, among others, are identified for resolution in later phases.

During the validation phase, preliminary designs and engineering are verified. Logistics problems, and others, are the subject of analysis and trade-offs. A formal requirements document is prepared.

During full-scale development, the system and all items necessary for its support is developed, assembled and tested. A decision is made as to whether the system is acceptable to enter the Army inventory.

During production and deployment the operational units are trained, the equipment is procured, and logistics support is provided.

The documents needed to substantiate the objectives and requirements in the acquisition process are:

(1) Operational Capability Objective (OCO) -- A description of an operational capability to be acquired in a time frame ten or more years in the future.

(2) Letter of Agreement (LOA) -- Describes the investigations necessary to validate the system concept and to define the operational, technical, and logistic concepts.

(3) Outline Development Plan/(ODP) -- Document to record to support the materiel system concept prior to and during the validation phase. The ODP includes as Section VI a plan for logistics support during advanced development. It includes identification of critical issues, recommended reliability, availability and maintainability goals, and plan for identifying logistics support resource requirements.

(4) Letter Requirement (LR)-- Provides an abbreviated procedure for acquisition of low value items. Low value items are low risk development for which total RDTE expenditures will not exceed $1 million and procurement costs for any one year will not exceed $2 million. The LR includes, as Section 7, Logistics Support Implications. Provided in this section are logistics constraints or considerations applicable to the design or development of the item.

(5) Required Operational Capability (ROC) -- A document describing the minimum essential operational, technical, logistical and cost information required for a HQ DA decision to pursue engineering development and acquisition.

(6) Training Device Requirement (TDR) -- A document describing the minimum essential performance characteristics, technical, logistical and cost information required for a HQ DA decision to pursue engineering development and acquisition of a training device.

5-3 IN-PROCESS REVIEWS

In-Process Reviews (IPR) are periodic decision points during the evolution of the system. The IPR serves to validate assumptions and rationale for the chosen alternatives. The IPR provides an opportunity for review of tests, experiments, and cost effectiveness studies and development plan updates. The IPR's are applicable to non-major systems. For major systems, the periodic decision point reviews are called Defense System Acquisition Review Councils (ASARC). For both major and non-major systems, the reviews include an examination of logistic support aspects of the

system, - e.g., support concepts, tools and test equipment recommendations, maintainability trade-offs and design for testability.

The essential characteristics in the ROC and the results of testing to verify meeting those characteristics are specifically examined during the review.

5-4 ACQUISITION REVIEW CHECKLIST

Tbles 5-1 through 5-5 present checklists for five categories of reviews. The checklists are oriented to maintenance concerns and can be adopted to specific projects or programs. The categories represent progressive stages in the acquisition, process from concept to production.

TABLE 5-1. SYSTEM PLANNING REVIEWS

1. System Support Concept
   a) Does it reflect the system support requirements?
   b) Is its development in step with the system concept?
   c) Does the support concept support the operational capability objectives?
   d) Is the support concept able to adjust to transients in workload?
2. Are design reviews planned, scheduled, and funded?
3. Life Cycle Impact
   a) Have support concept costs been anticipated over the service life of the system?
   b) Have alternative support costs been considered, evaluated and discarded?
   c) Does the support concept consider shared maintenance facilities, personnel, and logistics channels with contemporary, co-located Army systems?
4. Materiel Readiness
   a) Is the support concept, particularly at organizational and direct support level, related to operational availability objectives?
   b) Has the support workload been sized as a function of anticipated failure rates compatible with availability estimates?

TABLE 5-2. MECHANICAL/FUNCTIONAL REVIEW CHECKLIST

Informal Review

1. Use of Standard Circuits (where applicable)
   a. Does this also standardize test equipment?
   b. Does it reduce or eliminate critical adjustments?
   c. Are circuit types kept to a minimum?
   d. Have techniques for troubleshooting started to take shape?
   e. Do standards exist for calibrating test equipment?
   f. Should unusual test equipment be considered?
2. Circuit Simplicity
   a. Can auxiliary networks be removed without deteriorating function?
   b. Is built-in test equipment the best answer?
   c. Can adjustable circuits be further reduced?
   d. With the existing inputs and outputs, can any component be simplified or complexity reduced?
   e. Is complicated singularity or simplified redundancy better in any section?
3. Adjustment Requirements
   a. Are adjustments held to a minimum?
   b. Will component selections be made that will hold their settings?
   c. What test equipment and techniques will be required for adjustments?
   d. Will adjustments be in mandatory sequence, or are they independent?
   e. What tools will be required for adjustment?
   f. Is there interaction during adjustment?
   g. Can adjustments compensate for tolerance change?
   h. Will periodic adjustment or alignment be needed?
   i. Are adjustments and test points compatible?
   j. Will factory settings require readjustment on installation or during replacement?
   k. Will adjustment movement direction correspond to indicator movement? Zero center?
   l. Will attachment of test equipment unbalance any circuits?
4. Test Points
   a. Can test connections be maintained during adjustment?
   b. Are there sufficient test points?
   c. Are they identified as to function or use?
   d. Are they compatible with planned test equipment?
   e. Are they positioned relative to one another to minimize the electrical shock hazard?
   f. Are they designed so that no damage to system can occur by introduction of unwarranted signal?
5. Built-In Test Equipment
   a. Is all of the built-in equipment required during the mission?
   b. Can auxiliary equipment do as well without reducing effectiveness?
   c. Does the test equipment dynamically test parameters in question? Is it effective in predicting failures or is it to be used only after failure indication?
   d. After any failure indication can mission be completed on reduced basis? Has this been adequately documented?
   e. Are identifications and markings adequate?
6. Maintenance Plan
   a. Does the existing maintenance plan include coverage for all problems encountered including test and calibration equipment?

TABLE 5-2. MECHANICAL/FUNCTIONAL REVIEW CHECKLIST (Cont)

7. Relationship to Other Disciplines
   a. Have all other affected disciplines been kept current? Have they received adequate data for impact evaluation?
   b. Should extra meetings be held to clarify problems?
   c. Will all disciplines agree on solutions? Have minority opinions been documented/distributed adequately?
   d. Have trade-offs been justified/validated?
   e. Will testing reduce the life of item being tested? (None, some, appreciably, significantly?)

Formal Review—Subjects for Consideration

1. Maintenance plan
2. Standard circuits and electromechanical elements
3. Modular vs. nonmodular decisions
4. Adjustments required—criticality
5. Test points—adequacy, location
6. Built-in test equipment
7. Simplicity of design
9. Relationship with other disciplines
9. Support requirements
10. Advance planning for spares and manuals
11. Product safety

Formal Review—Checklist

1. Has an assembly specification been prepared?
2. Have characteristics of the critical parts been specified?
3. What are the assembly requirements and tolerances?
4. If no specification is prepared for critical components, how is acceptability to be determined?
5. How is the completed assembly to be tested?
6. What is labor and material cost per unit?
7. What are the mounting arrangements?
8. How are connections made to the assembly?
9. What is the effect of frequency interference?
10. What are the effective signal level limits?
11. Over what bandwidth must the assembly operate?
12. How and where will component parts be obtained?
13. How will it be assembled in the plant?
14. What environmental tests will the assembly be capable to meet?
15. What effect will assembly failure have on system operation?
16. How many are required per system?
17. What is assembly estimated life or mean-time-between-failures?
18. What trade-offs can be made to improve life?
19. What interface problems are anticipated? How are they to be handled?
20. What electrical tests are required to prove specification compliance?
21. What are the safety hazards involved with equipment design?

TABLE 5-3. EXPERIMENTAL/BREADBOARD REVIEW CHECKLIST

Informal Review

1. Are maintenance and test equipment requirements compatible with the maintenance plan?
2. Is design such that circuit damage will not result from careless adjustment procedures?
3. Have factory and maintenance test equipment been minimized and coordinated with other units?
4. Are special techniques required in repair, replacement, or alignment of units?
5. Are testing, alignment, and repair procedures such as to require minimum knowledge by repair personnel?
6. What special tools and test equipment are required?
7. Can every fault of any type which can occur be detected by use of proposed test equipment and procedures?
8. Have items subject to early wear-out been identified?
9. Have voltage dividers been provided for test points for circuits carrying more than 300 volts?
10. Will circuits tolerate use of a jumper cable?
11. Have all precautions been taken to protect personnel from mechanical, electrical, chemical, radiation, etc., hazards associated with the equipment?
12. Are special calibration features required?

Formal Review—Subjects for Consideration

1. Criticality of design as it affects maintenance—special parts selection, procedures, or spares?
2. Calibration requirements—are field calibrations reduced to minimum?
3. Test point application—enough of right type confirmed by tests?
4. Testing techniques and adequacy—any unusual methods or skills required?
5. Packaging concepts—what is to be the repairable unit? Is it accessible?
6. Reliability vs spares—reliance on reliable parts or on replacement? Trade-offs on spares vs space, weight, and cost. In-commission rate vs reliability figure of merit.
7. Support requirements—special equipment required for maintenance? Kind of skills and number of personnel? Specialized training required? Manuals?
8. Logistic interfaces—specially selected components required to make it work?
9. Ease of maintenance in the planned environment.
10. Cost of maintenance and possible savings.
11. Personnel hazards involved during manufacture, operation, and maintenance.

TABLE 5-4. PROTOTYPE RELEASE REVIEW CHECKLIST

Informal Review

1. Is this the best volume utilization, allowing for maintenance?
2. Will this type of construction allow plug-in replacement to shorten downtime, or is removal and replacement time longer than repair-in-place time?
3. Will this type construction survive the lifetime environment—shipping, temperature, humidity, shock and vibration? Will there be hot spots?
4. Will special tools or fixtures be needed for adjustment, test, or repair?
5. Can repairable subassemblies be tested and repaired at the bench without special tools or protection?
6. What are the techniques and location for repair—on site, in depot, in factory?
7. Will cooling be adequate during maintenance?
8. Have guide pins been provided to facilitate installation of plug-in units?
9. Are plug-in units keyed to prevent insertion errors?
10. Has protection been provided for cabling around corners or near sharp edges?
11. Are grommets provided wherever necessary?
12. Will design minimize chance of soldering iron burns?
13. Can units be dynamically tested in place?
14. Is there clear access to all removable items?
15. Are all test points readily accessible as installed?
16. Are all adjustment points accessible as installed?
17. Is there adequate provision for protection of test and maintenance personnel against injury?
18. Is each assembly self-supporting in the desired positions for testing and maintenance?
19. Can assemblies or units be laid on a bench in any position without damaging components?
20. Are displays located for easy observation during testing?
21. Do functionally related controls and displays maintain functional or physical compatibility, i.e., direction of motion and physical proximity?
22. Do design, arrangement, and installation allow adequate working space?
23. Do chassis and panel fasteners require special tools? Are there too many, thus hampering access?
24. Are units light enough for ease of removal? Have adequate handling devices been provided?

Formal Review

1. Specification compliance:
   Maintainability goal vs. attained maintainability.
2. Producibility vs maintainability:
   Will any maintainability features be compromised by necessary production techniques?
3. Failure records vs maintainability:
   Have failures and corrective actions revealed any loopholes in maintainability?
4. Engineering changes vs maintainability:
   Will any changes made or completed compromise maintainability?
5. Are there any last minute changes that can be made to improve maintainability?

AD-A040 129 RCA GOVERNMENT SYSTEMS DIV BURLINGTON MASS AUTOMATED--ETC F/G 15/5
TEST ACCESSIBILITY DESIGN GUIDE FOR ARMY MECHANICAL, HYDRAULIC --ETC(U)
SEP 76 F W HOHN, K G HOPKINS, R C BLANCHARD DAAA25-75-C-0681
UNCLASSIFIED FA-FCF-10-76 NL

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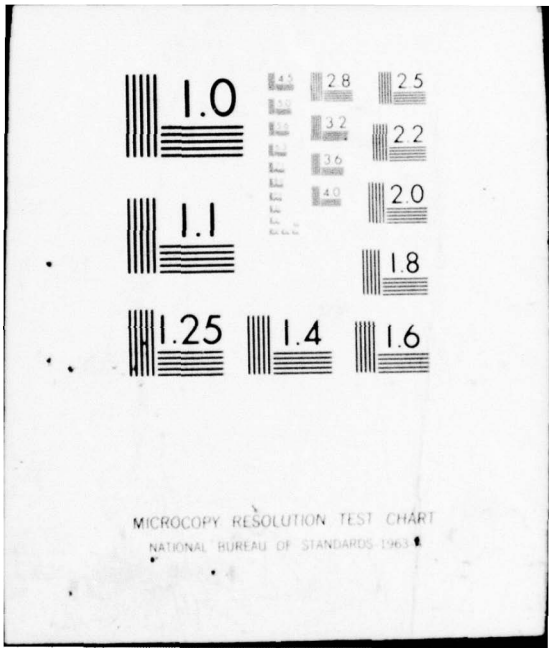

1.0
1.1
1.25
1.4
1.6
2.8
2.5
3.2
2.2
3.6
2.0
4.0
1.8
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963

TABLE 5-5. SUPPORT FACILITIES REVIEW CHECKLIST

Objectives

1. Tools and shop facilities
2. Test equipment
3. Personnel requirements
4. Skill and training requirements
5. Documentation requirements
6. Installation requirements
7. Loading (peak usage demands)
8. Spares requirements and distribution
9. Transportation requirements

Criteria

1. Adequacy of planning or coverage
2. Criticality of objective to mission accomplishment
3. Timeliness of planning, development, and delivery
4. Availability of existing materiel
5. Standardization
6. Trade-offs
7. Cost
8. Interface compatibility
9. Failure effects

Checklist

1. Are maintenance and test equipment requirements compatible with the concept established for the system?
2. Does any unit require special handling? Has the handling facility been provided?
3. What adjustments are required after installation of unit and of the system?
4. Is periodic alignment, adjustment, or servicing required? How often?
5. Are the procedures for testing, alignment, or repair written to require minimum knowledge on the part of maintenance personnel? Are they too specific?
6. Have all special tools and test equipment requirements been identified? Has action to procure special tools and test equipment been started?
7. Have all shop facilities requirements been identified and provided for (all types of power, heating and resealing, and evacuating, etc.)?
8. Have shipping methods, containers, and lead time been planned? Are containers designed to permit testing of contents without removal from package?
9. Are the planned manuals and charts the best that can be provided?
10. Has an adequate data collection system been established?
11. How are spares to be selected?
12. Where will spares be maintained?
13. What effect will lead time have on spares provision or replacement?
14. What are the spares packaging and storage requirements? Are there any exceptions?
15. Is the spares policy compatible with the design (prime) packaging concept?
16. Do any spares require servicing, testing, or adjustment?
17. Do any spares have limited shelf life? Replacement schedule established?
18. Are there special parts spares that should be procured in lifetime quantities to avoid reprocurement problems?
19. What calibration facilities will be required?
20. Are the spare parts, manuals, and maintenance plan for test equipment established?

SECTION II

DESIGN REVIEWS

5-5 GENERAL

Design reviews are conducted throughout the product design cycle, in accordance with contract requirements, as an integral part of the system engineering review and evaluation program. The reviews are conducted so that particular aspects of the work or the entire system can be reviewed by a Design Review Board, an objective group of program personnel and specialists in the particular field. Reviews are scheduled and the board is appointed by the program management, upon recommendations of the various specialty groups, in order that deficiencies in equipment can be recognized to facilitate the implementation of timely and beneficial corrective action.

In addition to the chairman, the Design Review Board may include representatives of the following organizations: Maintainability, Reliability, Test and Evaluation, Design and Development, Manufacturing Engineering, and Quality. Consultants from outside agencies, vendor and subcontractor representatives, and military personnel may be included if appropriate. It is important that appointed representativesbe technically qualified but not be so closely related to the product that an objective viewpoint is precluded.

Examples of the factors to be considered in a review (not necessarily in order of priority) are reliability, cost, environmental design, maintainability, human engineering, system concept, producibility, quality, test philosophy, installation, design, safety, and standardization.

5-6 MAINTAINABILITY DESIGN REVIEW RESPONSIBILITIES

The activities that should be performed by the maintainability engineer as part of his design review responsibility are as follows:

(1) Prepare and present quantitative assessment of maintainability.

(2) Prepare and present task analyses, if required.

(3) Prepare and present a list of design features that are most detrimental to maintainability or constitute a safety hazard.

(4) Report any changes in maintenance concept or support equipment required as a result of design changes.

(5) Present results of any trade-off analyses in which maintainability was a major contributor.

(6) Recommend design changes that will improve maintainability or that will trade off excess maintainability to eliminate inadequacies in other areas.

(7) Present interface problems.

(8) Report progress toward milestones.

(9) Report on personnel and skills required for system operation and maintenance.

(10) Define preventive maintenance and corrective maintenance requirements.

5-7 DESIGN REVIEW INPUT INFORMATION

Information provided to the review team prior to the review must describe the item being reviewed and its requirements and interfaces. For example, component review for an item built in house might require the following documentation:

(1) Detail drawing (pictorial representation, descriptions of required materials, finish, dimensions, tolerances, fabrication, and assembly instructions, etc.).

(2) Installation drawing (general configuration, attaching hardware, and information to locate, position, and mount the item).

(3) Component specification (functional characteristics and test requirement).

(4) Data on parts and materials application.

(5) Subsystem (or system) specification (for interface functional characteristics and test requirements).

(6) System design data report (system description and specific design requirements such as space and weight considerations, mounting requirements, special environments, design and checkout requirements, maintenance provisions, etc.).

(7) System design criteria report (general design philosophy and ground rules).

(8) Reliability analyses and failure mode and effects analyses.

The last four documents listed provide interface information and should reflect the latest equipment operational profile. One task of the review effort will be to verify that all changes in the equipment's operational profile have been implemented and that the component requirements have been re-evaluated. The major product of such a re-evaluation of requirements is assurance that

the design is capable of performing any new task under possibly increased environmental stresses. The re-evaluation also gives assurance that major design simplifications have been accomplished, when possible, to take advantage of associated reliability and cost benefits. This discussion is included here since the proposed evaluation of mission changes should be performed in the preparatory phase rather than during the design review meeting. The devotion of any portion of the design review effort to obsolete design criteria is thus avoided.

Subcontractor items receive similar consideration, except that the effort is usually divided into two phases: one at the contractor facility and one at the vendor facility. The initial phase includes review of interface and installation documents, as described above, to confirm the accuracy of the requirements in the component (or procurement) specification. The procurement specification is usually expanded to include not only performance requirements but details such as external dimensions, finish, and mounting surfaces with specific design detail being let to the vendor, who must document and incorporate them into the specification.

In addition to the specific documents referenced above, a review requires other, more general types of information. Documented results of prior reviews, with management approval or disapproval and summaries of followup action, provide topics for current discussions. The designers must bring to the review all pertinent supporting data; e.g., design and laboratory notebooks, test reports, analyses, results of part and material application reviews, etc. Similarly, the reviewer should be prepared to support his position with data.

5-8 DESIGN REVIEW OUTPUT INFORMATION

Documentation of a design review must include the logic behind discussions about corrective action. The usual listing of action items is inadequate by itself, since the logic behind rejecting recommendations may be more significant. Design review is basically a management decision making tool, and management interest at a later date may center on one of the "no action" items. The reason for repeated rejection of that item by the review team will assist management in evaluating new information. The same reasoning applies to later review efforts.

Design review documentation must record the team makeup, the review level, the input materiel the decision items (not merely

action items), and the decision logic when it is not evident. It must be of sufficient depth to be useful in subsequent reviews and to assist management in approving recommended action.

The report should have the concurrence of all review attendees. It should be prepared as the meeting progresses, with each item being resolved before the meeting continues. Although this may appear to be prohibitively time consuming, the advantages usually outweigh the inconvenience. The advantages include the following:

(1) Added incentive for careful preparation. Prior research and written conclusions are more likely to receive recognition than an educated guess made during the review.

(2) Added directional control of the meeting. The chairman has a valuable tool in immediate documentation because it tends to keep the meeting objectives in focus. By rephrasing discussion thoughts into wording suitable for the report, he continually directs attention to the need for applicable rather than extraneous data.

(3) More accurate recording of consensus. Post-meeting documentation is dependent on one person's interpretation of meeting conclusions, and its preparation is usually delayed. Both of these conditions permit distortion.

(4) Promotion of timely corrective action. Point-by-point agreement prevents major delays resulting from disagreement with the accuracy of the recorded version of the meeting.

If it is not considered feasible to prepare the report during the meeting, then, as a minimum, a summary agreed upon by all attendees must be written before the meeting ends. This summary will serve as the basis for the subsequent report.

5-9 DESIGN REVIEW PROGRAM

The design review meetings scheduled for any design program should include the design concept review, preliminary design review, and the critical design review. Table 5-6 is a summary of the major design review considerations.

TABLE 5-6. SUMMARY OF MAJOR DESIGN REVIEW CONSIDERATIONS

Major Considerations	Design Concept Review	Preliminary Design Review	Critical Design Review
1. Select design alternative.	X		
2. Present maintainability block diagram	X		
3. Review program data requirements.	X	X	X
4. Review adequacy of design information.	X		
5. Present maintainability prediction of selected design.		X	X
6. Present maintenance concept.		X	X
7. Present testing concepts.		X	
8. Review environmental constraints.		X	
9. Assure that all design requirements have been met.	X	X	X
10. Review all system trade-offs.		X	X
11. Present maintainability demonstration test results.			X
12. Recommend design changes as required.		X	X

SECTION III

TRADE-OFFS

5-10 MAJOR SYSTEM TRADE-OFFS

To meet overall system requirements within a budgeted cost and fixed frame time, trade-offs are often necessary among the major system parameters. Trade-offs within the major parameters are also necessary to attain the specified levels for each parameter. In the case of maintainability, a trade-off may be effected with reliability to achieve the desired availability. At the same time, however, mission requirements may dictate a minimum maintainability requirement, below which a trade-off may not be made. In this situation, trade-offs among the parameters of maintainability (design, personnel, and support), or among the components of the system, may be necessary to achieve the required maintainability level. The following paragraphs give techniques for performing these trade-offs with the system, between components (subsystems) of the system, and between maintainability tests.

5-10.1 SYSTEM AVAILABILITY TRADE-OFF

The all important goal in equipment design is equipment availability. The availability of a weapon system is determined principally by its maintainability - the ease with which it can be kept ready to respond to the tactical need when needed. The requirement for maintainability must be periodically reassessed as design progresses, on the basis of a practical analysis of the inherent "repairability" characteristic of the design. Availability is dependent upon the probability of system repair and return to operational status, and is dependent on reliability and maintainability through the following relationship:

$$A_i = \frac{MTBF}{MTBF + MTTR}$$

where

A_i = inherent availability; the probability that a system or equipment, when used under stated conditions, without consideration for any scheduled or preventive maintenance and in an ideal support environment, will operate

satisfactorily at any given time. Excludes ready time, supply downtime, waiting or administrative downtime, and preventive maintenance downtime.

MTBF = mean-time-between-failures.

MTTR = mean-time-to-repair; the average time required to detect and isolate a malfunction, effect repair, and restore the system to a satisfactory level of performance.

Since availability reflects two fundamental measures of system dependability, namely, MTBF and MTTR, its use in analytically evaluating a system is advantageous.

5-10.1.1 Nonredundant System

Figure 5-1 illustrates the use of availability for trade-offs for a weapon system. The system is depicted as containing five subsystems for which the reliability and maintainability have been predicted. Table 5-7 summarizes the MTBF, MTTR, and inherent availability for each subsystem of the nonredundant system (Figure 5-1(A)). The system availability, A_S, is calculated by forming the product of the individual availabilities, assuming independence of A_i as follows:

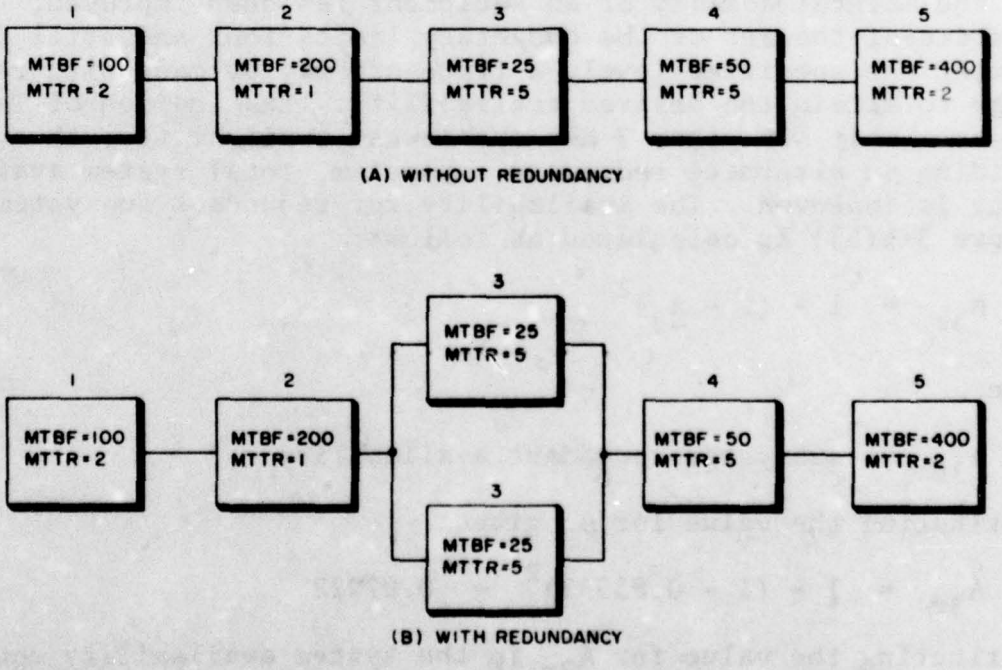


Figure 5-1. Using Availability for Trade-Offs in a Weapon System

TABLE 5-7. WEAPON SYSTEM AVAILABILITY WITHOUT REDUNDANCY

Subsystem	MTBF	MTTR	A_i
1	100	2	0.98039
2	200	1	0.99502
3	25	5	0.83333
4	50	5	0.90909
5	400	2	0.99502
Resultant A_s = 0.73534			

$$A_8 = A_1 \times A_2 \times A_3 \times A_4 \times A_5$$

Using this formula, the availability for weapon system A is:

$$A_8 = (0.98039) \times (0.99502) \times (0.83333) \times (0.90909) \times (0.99502) = 0.73534$$

5-10.1.2 Redundant System

If the maintainability of an equipment has been improved, to the state-of-the-art or the budgetary limitations and still does not meet the specified level, a trade-off may be made with reliability to attain the desired availability. Examination of Table 5-7 shows that subsystem 3 has the lowest availability; thus by providing an alternate redundant subsystem, total system availability is improved. The availability for redundant subsystem 3 (Figure 5-1(B)) is calculated as follows:

$$A_{3r} = 1 - (1 - A_3)^2$$

where

A_{3r} = subsystem redundant availability

Substituting the value for A_3 gives

$$A_{3r} = 1 - (1 - 0.83333)^2 = 0.97222$$

Substituting the value for A_{3r} in the system availability equation gives:

$$A_8 = (0.98039) \times (0.99502) \times (0.97222) \times (0.90909) \times (0.99502) = 0.85790$$

The introduction of redundancy for subsystem 3 has resulted in an increase in total system availability.

5-10.1.3 Basic System Plus Support Equipment

An alternate method increasing availability is to increase the maintainability of the system through a trade-off between the design and support parameters. This can be accomplished by placing much of the burden on the support parameter. As an example, assume that a sophisticated maintenance check-out equipment is developed for the weapon system (Figure 5-1), which reduced the maintainability requirements for the weapon system by one-half. The availability achieved by this alternate method is given in Table 5-8 and is calculated as follows:

$$A_8 = (0.99009) \times (0.99751) \times (0.90909) \times (0.95238) \times (0.99751) = 0.85296$$

TABLE 5-8. WEAPON SYSTEM AVAILABILITY TRADE-OFF WITH SUPPORT EQUIPMENT AND REDUNDANCY

Subsystem	MTBF	MTTR	A_i
1	100	1.0	0.99009
2	200	0.5	0.99751
3	25	2.5	0.90909
4	50	2.5	0.95238
5	400	1.0	0.99751
Resultant A_s = 0.85296			

Again a substantial gain has been achieved but at a greater system cost. An additional degradation factor may be the potential unavailability of the support equipment. This factor may be analytically treated to incorporate the degradation into the weapon system availability.

5-10.1.4 Selection of Best Method

To select the best method for improving availability, the relative cost for each approach must be estimated for the example given. Table 5-9 gives the development costs for each configuration (assuming equal performance capabilities). From this data, configuration II is shown to have the highest availability with the least increase in development cost.

TABLE 5-9. SUMMARY OF WEAPON SYSTEM PARAMETERS

Configuration	Development Cost	Availability
I Basic System	$500,000.00	0.73534
II Redundant System	$550,000.00	0.85790
III Basic System Plus Support Equipment	$560,000.00	0.85296

5-10.2 COMPONENT AVAILABILITY TRADE-OFF

The technique described for trading off maintainability against reliability at the system level is also applicable at the subsystem, equipment, and component levels. Basically, at the component level, the costs of increasing reliability and maintainability through redesign are calculated for various levels of each attribute. The availability for each combination of reliability and maintainability levels is calculated along with the associated development cost. These data are then tabulated, as in Table 5-9 and the method for improvement is selected on the basis of mission requirements and budgetary limits.

5-11 MAINTENANCE TESTING TRADE-OFFS

The checkout of a complex equipment and system can be accomplished either individually or by a combination of the following testing concepts:

(1) System tests. Exemplified by a control system, transmitter system, or navigational system; an integrated grouping of associated elements which accomplish an operational task. This requires the system to be subjected to stimuli necessary to simulate operational conditions and the response evaluated for abnormalities.

(2) Component tests. Typified by amplifier units, power supplies, memory storage devices, or displays; an integrated group of associated elements which perform a defined function and are packaged in a transportable or removable unit. The test is performed to demonstrate whether a component or individual elements within a component are operating within tolerances.

(3) Static tests. Performed through use of non-varying stimuli, such as signals with constant or zero current. The item under test is not subjected to the variety and magnitude of stresses encountered while in operation.

(4) Dynamic tests. Tests which simulate or reproduce functional modes, and in so doing exercise individual elements of unit under test.

(5) Open-loop tests. Measures direct response of an item to changes in the several parameters (including external requirements and characteristics of other items) affecting it without regard to remainder of the system. However, no adjustments are made to stimuli because of that response.

(6) Closed-loop tests. Represents response of an item to changes in the several parameters affecting it, and where feedback through other systems is taken into account.

(7) Marginal testing. Provides information relative to the ability of components to operate under full range of design parameters. Upon application of stimuli (varying bias voltages, frequency, mechanical speeds, or temperature under controlled conditions) during field maintenance, individual piece-parts or components can be made to function close to the design tolerance limits. The test can be used to detect component degradation or to establish a confidence level of performance.

The decision to use one or another type or combination of testing techniques entails consideration of factors such as: the stability of the circuit, type of system, cost, personnel training and skill, time permitted for testing, test information required, maintenance level at which tests will be performed, readout instrumentation required, sequencing of tests, environment and installation, and whether testing of a particular kind reduces life of item.

5-11.1 CATEGORIES OF TEST EQUIPMENT

The three types of test equipments defined below are representative of equipment currently in use.

(1) Special purpose (SP). Test equipment designed for a unique use pertaining to a particular system.

(2) General purpose (GP). Test equipment usable in different systems; generally available as an "off the shelf" item in government or commercial inventories.

(3) Built-in test equipment (BITE). Equipment which is an integral part of prime equipment or system; cannot be readily detached or separated from basic equipment. Normally typified by "press-to-test" procedures.

Each type may be manual or automatic.

5-11.2 SELECTION OF TYPES OF TEST EQUIPMENT

A decision regarding the proper type of test equipment to be used must be made in the early stages of prime equipment design - as early as the drafting of the maintenance support plan will allow - and should be firm by the system and subsystem development stage. The factors involved in this decision include: the mission and operational characteristics of the equipment, the anticipated reliability, the maintenance structure, equipments and personnel available to the user, the operational environment, logistical support requirements, development time, and cost. Table 5-10 compares special purpose, general purpose and built-in test

TABLE 5-10. FACTORS IN TEST EQUIPMENT SELECTION

Factor	Element	Rating		
		Built-in	Special Purpose	General Purpose
Maintenance Technician	Personnel acceptance	High	Medium	Low
	Personnel safety	High	High-Medium	Medium-Low
	Complexity of test equipment operation	Low	Medium	High
	Time to complete tests	Least	Medium	Most
	Personnel training time	Least	Medium	Most
	Tendency to over-depend on test equipment	High	High	Low
Physical Factors	Limits on size of test equipment	Minimum limits—depends on prime equipment and application		Maximum limits—limited by portability
	Limits on weight of test equipment	Minimum limits—depends on prime equipment application		Maximum limits—limited by portability
	Complexity of "wiring in" test equipment	High	High	Low
	Need for additional test points in prime equipment	None	None	Many
	Wasted space in work areas	Least	Some	Most
	Storage problems	None	None	Many
	Need for traffic considerations	Low	Medium	High

TABLE 5-10. FACTORS IN TEST EQUIPMENT SELECTION (Continued)

Factor	Element	Rating		
		Built-in	Special Purpose	General Purpose
Application	Advantage of long duration and high frequency usage in given location	High	High-Medium	Low
	Versatility of application	Low	Low	High
	Opportunity for incorrect usage	Low	Low	High
	System adaptability to new test equipment	Low	Medium	High
Maintainability and Reliability	Probability of test equipment damage	Low	Low	High
	Probability of damage to prime equipment caused by testing	Low	Low	High
	Effect on prime equipment operation when repairing test equipment failures	Some	Slight	None
Logistics	Cost to incorporate test equipment	High	Medium-High	None
	Test equipment procurement time	High	Medium	Low
	Design engineering effort	High-Medium	High-Medium	Low
	Compliance of test equipment to same specifications as prime equipment	Must	May	May

equipments in regard to these factors.

The design engineer must determine the most important factors for a given equipment and make his decision accordingly. The paragraphs which follow present design criteria to aid the engineer in making his decision. Recommendations for the design of specific types of test equipment are given in Chapters 14 through 19.

5-12 APPLICATION OF NSIA TRADE-OFF TECHNIQUE

At the U.S. Army Mobility Equipment Research and Development Center (MERDC), Fort Belvoir, Virginia, this trade-off technique has been used in a maintainability study for an item of Army equipment, a diesel-drive tractor. The study was conducted to ascertain the degree of desirability of proposed design changes to improve the maintainability of the item. Evaluation was made by means of a complete tear-down of the equipment through organizational level of maintenance under simulated field conditions.

5-12.1 DESIGN PROBLEM

The specific problem was to redesign the connecting elements of the front, center, and rear sections of the tractor so that three organizational maintenance personnel could, in one hour, install or remove the center section from the front and rear sections, and uncouple or couple-up the front and rear sections. In addition, the operation had to be performed with the tools and support equipment available at the organizational level. Table 5-11 illustrates the application of the trade-off technique to the problem, and the concluding results. A graphic summary of the evaluation is presented in Figure 5-2.

5-12.2 PRECAUTIONS FOR USE OF NSIA TECHNIQUE

To reduce or minimize any bias that may be introduced through subjective evaluation, the following precautions should be considered when making a maintainability evaluation:

(1) Evaluations should only be made by individuals qualified to do so, i.e., experts.

(2) Evaluations of a single area of consideration should be made, whenever possible, by more than one expert on an independent basis, and the algebraic average of all evaluations used. If evaluations cannot be made independently, they should be made on a group basis. The larger the number of qualified evaluators that comprise the group, the more accurate and unbiased the final evaluation should be.

(3) Any bias that might be introduced by the opinion of an individual, or a group, is modified in its effect upon the final value because it is only one of several other factors. It is necessary, therefore, that all possible areas of influence be listed as parameters for consideration and evaluation and that each parameter be evaluated with respect to all possible areas of influence to maximize this effect.

5-13 MAINTAINABILITY TRADE-OFFS

Maintainability is defined in MIL-STD-721 as "a characteristic of design and installation that is expressed as the probability that an item will be retained in or restored to a specified condition within a given period of time when the maintenance is performed in accordance with prescribed procedures and resources". To design for maintainability is to incorporate features that reduce the resources (time, manpower, personnel skills, test equipment, tools, technical data, or facilities) required to perform maintenance. The following specific areas serve in the planning

TABLE 5-11. TRACTOR CENTER-SECTION REMOVAL TRADE-OFF EVALUATION

Parameters	Consideration	Relative Weighting	Basic Reading		Adjusted Value	
			Present	Proposed	Present	Proposed
Maintenance Time	Present - 8 hours Proposed - 1 hour	4	-70	+70	-280	+280
Maintenance Personnel	Present - 1 mechanic and 2 helpers Proposed - 1 mechanic and 2 helpers	3	0	0	0	0
Maintenance Facilities	Present - Special tools and crane Proposed - Crane, no special tools	3	-40	+60	-120	+180
Logistic Support	Present - Special bolts, gaskets Proposed - Standard parts	2	-10	-10	-20	-20
Weight & Space	No net effect	1	0	0	0	0
Performance	No net effect	0	0	0	0	0
Fabrication Cost	Proposed will cost some more	1	+10	-20	+10	-20
Production Schedule	No net effect	0	0	0	0	0
Reliability	Proposed design: less thread stripping	2	-30	+20	-60	+40
Safety	Proposed design: less hazards	2	-30	+20	-60	+40
Environmental Influence	No net effect	0	0	0	0	0
Human Factors	Proposed design will provide simpler and faster installation	4	-40	+60	-160	+240
Operation	No net effect	0	0	0	0	0
Totals		22			-690	+740

Calculations: Average net value—present design: $-690 \div 22 = -31$
Average net value—proposed design: $+740 \div 22 = +34$

Conclusion: The desirability of the proposed change, after considering effect on all parameters, is indicated by the magnitude of the total spread between the average net values -31 and +34 for a total value of 65 (see associated graphic summary chart, Figure 5-2).

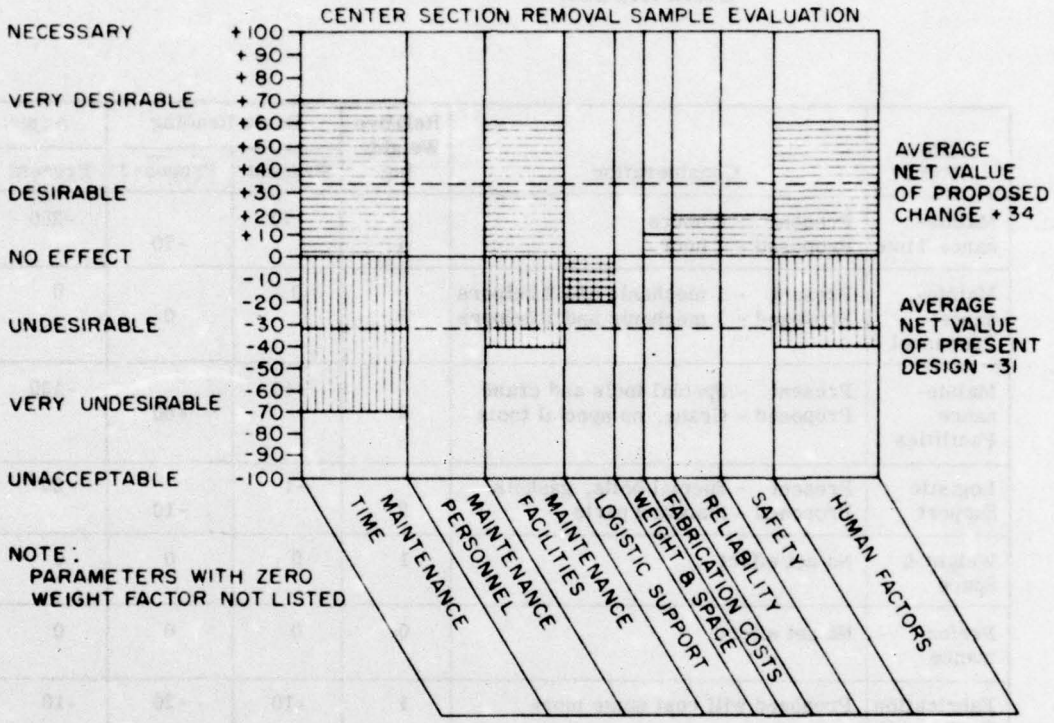


Figure 5-2. Tractor Center-Section Removal Trade-Off Evaluation, Graphic Summary

process as a point of departure from which specific measures can be developed, for coordination of these and any other disciplines in a program with respect to maintainability:

(1) Analytical techniques
(2) Maintainability analysis
(3) Maintainability demonstrations.

Implementation of maintainability features in the preliminary design of mechanical hydraulic and pneumatic equipment requires the development of a maintainability program as described in MIL-STD-470. The standard describes in detail those tasks or elements that must be incorporated into a maintainability program to assure effective, timely, and economical accomplishment of maintainability design objectives.

The maintainability program plan should begin with the preliminary design phase. Included in the program are:

5-13.1 DEVELOPMENT OF A PRELIMINARY CONCEPT

The preliminary maintenance concept is based upon the proposed operational requirements for the Army maintenance support structure. The maintenance concept is a summary of the total maintenance planned to assure proper functioning of the vehicle and its equipment to meet the operational requirements. Distribution of the maintenance concept to appropriate design personnel is required to insure their understanding of the maintenance environment and resource constraints of the design. The preliminary maintenance concept should be updated whenever factors affecting the original concept are identified.

5-13.2 PARTICIPATION IN DESIGN TRADE-OFF STUDIES

This is required to evaluate the effects that alternative designs would have upon the system maintenance requirements. As a minimum, trade-off studies present the relationships between alternatives based upon:

(1) Mean-time-to-repair (MTTR)
(2) Personnel skill requirements
(3) Training requirements
(4) Maintenance resource requirements.

Ideally, the trade-off study findings would rank design alternatives in the order of their demand for maintenance resources. The maintainability prediction techniques outlined in MIL-HDBK-472 are useful for establishing the necessary parametric values used in trade-off analysis.

5-13.3 PARTICIPATION IN DESIGN REVIEWS

Participation of maintainability engineering personnel in formal and informal design reviews is required to insure that continuing attention is given to maintenance considerations as the design evolves. The design review provides a means of exchanging information regarding maintainability problems and solutions, and of coordinating maintainability engineering inputs with those of the structural, reliability, manufacturing, quality assurance, and human engineering disciplines.

5-13.4 IDENTIFICATION OF POTENTIAL MAINTENANCE PROBLEMS

This is a continuing responsibility of the maintainability engineer. Some potential problems are:

(1) Use of subsystems or equipment that have known high failure rates

(2) Nonoptimum routine maintenance schedules
(3) Lack of accessibility to installed equipment
(4) Hinderances to equipment fault isolation capability
(5) Any apparent excessive maintenance resource demands
(6) Undue complexity of maintenance tasks
(7) Hazardous conditions and procedures
(8) Undue complexity of system design.

5-13.5 DEMONSTRATION OR VERIFICATION OF REQUIREMENTS

As part of any maintainability program, provisions must be made for the continuous monitoring of data that can be compared with predicted values. This is required by MIL-STD-473 and is important especially during the early test phases before the system enters operational service.

Paragraphs 5-13.1 and 5-13.2 are essential to the preliminary design phase and paragraphs 5-13.3 through 5-13.5 are essential to the development and qualification phases.

5-14 VALUE TRADE-OFF CONSIDERATIONS

In the planning and procurement of mechanical, hydraulic and pneumatic systems, operational support has often been unduly compromised in favor of performance, size, and weight. The effectiveness of a system is the probability that it will achieve success in performing its required mission. One measure of effectiveness, then, is availability. In this era of increased military system complexity, and pre-programmed maintainability, one must consider maintenance and logistics support early in the system design. Emphasis must be placed on achieving the proper balance between compatibility, logistics and performance by considering the factors which establish the performance and logistics standards early in the design process and through judgment and trade-off analysis.

5-14.1 VALUE FACTORS

The application of systems effectiveness principles to compatibility design requires consideration of the significant factors to be traded off. The data from which these decisions are made is generally based on a review of the operational concept, followed by a period of data collection from various sources, and data consolidation for use in effectiveness analysis. Depending on the complexity of the system and the scope of the program, factors to be considered in compatibility tradeoff decisions are:

(1) Deployment factors: number of systems, organizational structure, relation of groups, mobility, hierarchy and number of support installations, utilization rate of equipment, attrition rate.

(2) Prime equipment factors: equipment breakdown, failure rates, failure modes, physical characteristics, construction (WRA, SRA, modules, circuits), cost per equipment/WRA/module, required availabilities, human factors.

(3) Maintenance support factors: test equipment characteristics, special support equipment, interface devices, repair times, checkout times, manpower requirements/training, test program cost.

(4) Logistics factors: sparing policies, configuration control, supply times, production lead time, stockpile facilities, transportation factors, program update/modification.

Formulas, approaches, and specific computer programs have been developed which consider sensitivity and the influence of multiple factors in the total cost of ownership of the system by the customer. It is further possible to analyze this complete cost of ownership in terms of the life cycle spans involved. Through application of an existing mathematical model, it is possible to explore a matrix involving many different maintenance policy approaches versus the following four levels of support: equipment (built-in test), organizational, intermediate, and depot.

Included is the capability to insert into the basic formulas all significant logistics support factors and to obtain computer printouts of life cycle cost under many combinations of the maintenance and support philosophies involved. This printout directly shows the lowest cost approach. Factors can be further refined and adjusted to show the sensitivity of costs to significant parameters, thereby providing quantitative data for optimum planning.

Perhaps of equal significance is the influence of ILS systems engineering tradeoffs on equipment design. The results of studies which highlight potential operational benefits and greater resource utilization can also highlight the related equipment design features. These may include the type and capability of test equipment and certain prime system design features related to the economics of support, including the interface between the test equipment and the prime equipment.

5-14.2 RELATIVE WEIGHTING OF SUPPORT COST FACTORS

To make value judgements, it is important to examine the basic elements contributing to life cycle costs of military equipment.

The example shown in Figure 5-3 clearly shows that support costs during the life cycle can sometimes dwarf the prime equipment or initial system investment cost in prime equipment. It also points out that design tradeoffs should favor factors that will decrease support manpower spares and inventory.

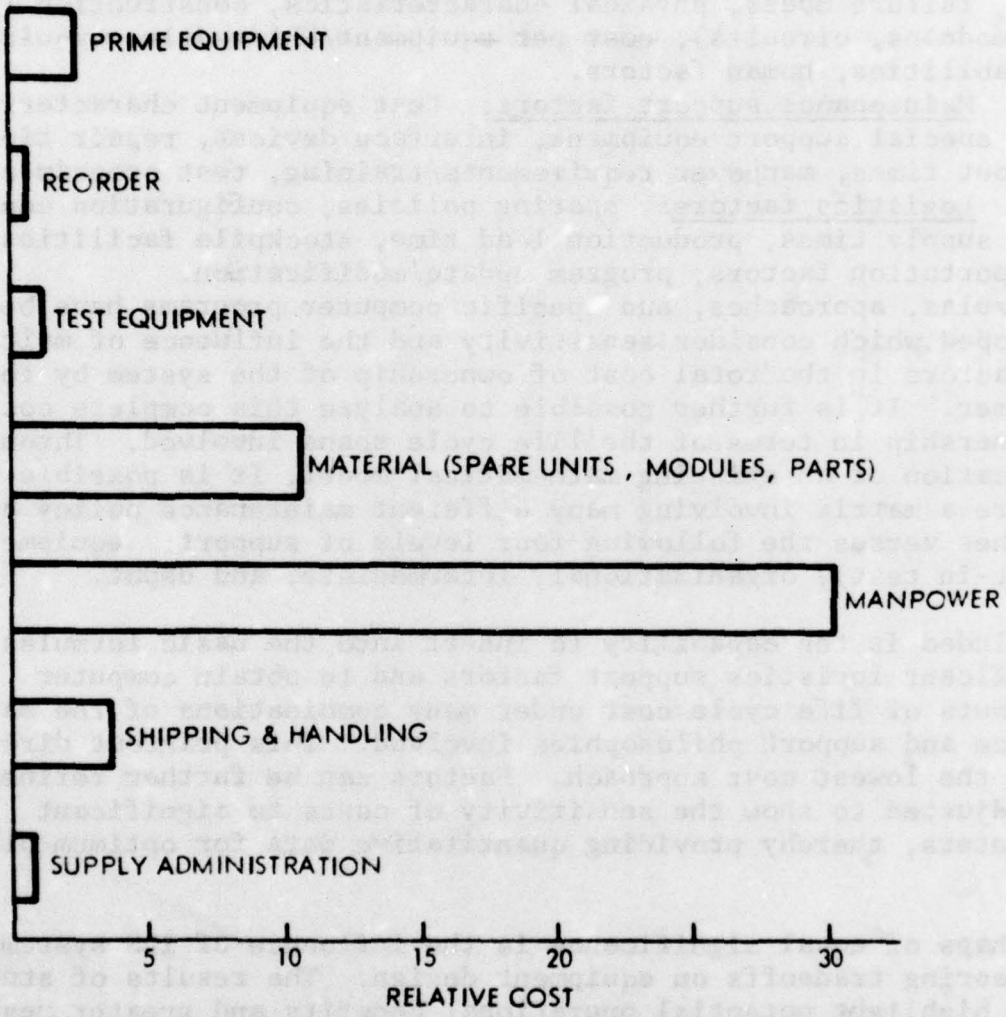


Figure 5-3. Comparison of Life Cycle Cost Elements

5-14.3 THE TRADE-OFF DECISION

Tradeoff decision is part of everyday routine. Every design decision is based on judgement, which in turn represents the weighing of known facts. The greater the number of facts dealt with objectively and systematically, the greater the probability of arriving at a correct decision.

Tradeoffs play a primary role in decision-making during design review, when the diverse interests of several project objectives must be reconciled. It must be emphasized, however, that all factors which influence the ultimate outcome of the analysis must be considered if the quantitative basis for comparison of alternatives is to be valid.

The various trade-off techniques in use, such as the National Security Industrial Association (NSIA) technique*, are superior to any qualitative method for estimating the relative desirability of design features. The NSIA trade-off technique produces positive or negative numerical values for the possible effects of a particular design feature on all the characteristics of the system. To illustrate the general trade-off procedure, a step-by-step description of the application of the NSIA technique is shown below. The evaluator uses numerical values for estimating favorable and unfavorable effects. In general:

(1) Define the problem to be resolved

(2) List possible solutions, eliminating those which for obvious reasons would not be acceptable.

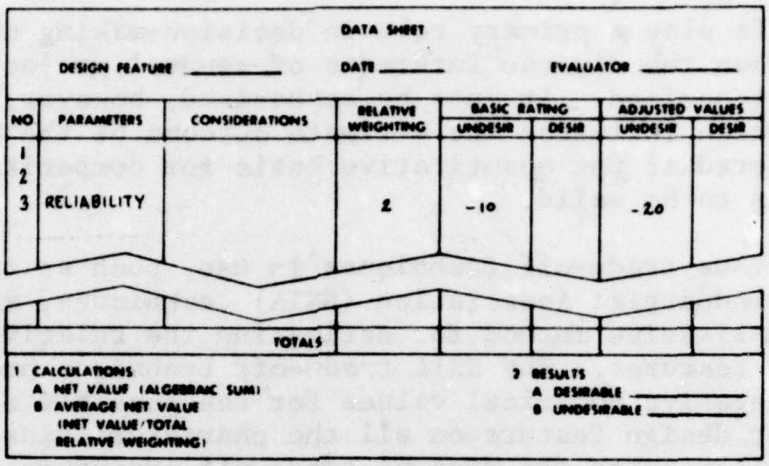
(3) Clearly define each solution and, for each solution, enter on the data sheet (Figure 5-4) the following:

(a) The parameters affected by each design approach, e.g., avionics equipment, ATE system, special test equipment, interconnection device, programming, training, size, weight, reliability, etc.

(b) Biasing information about any parameter in the "consideration" column: e.g., system variables that affect the normal weighting factors for the parameter.

(c) The relative weighting for each parameter: i.e., a weighting factor that represents the relative importance of the parameter to overall system performance. Assign a value of unit to the least important parameter and appropriate whole-number values to the others, according to their importance. The weighting of each parameter cannot be generalized since the relative importance of any parameter is unique to each program.

*Department of the Army Pamphlet 705-1, Research and Development of Material, Maintainability Engineering Headquarters, Department of the Army, 1966.



DATA SHEET

DESIGN FEATURE _____ DATE _____ EVALUATOR _____

NO	PARAMETERS	CONSIDERATIONS	RELATIVE WEIGHTING	BASIC RATING		ADJUSTED VALUES	
				UNDESIR	DESIR	UNDESIR	DESIR
1 2 3	RELIABILITY		2	-10		-20	
		TOTALS					

1 CALCULATIONS
A NET VALUE (ALGEBRAIC SUM)
B AVERAGE NET VALUE (NET VALUE/TOTAL RELATIVE WEIGHTING)

2 RESULTS
A DESIRABLE _____
B UNDESIRABLE _____

Figure 5-4. Data Sheet for NSIA Tradeoff Technique

(d) The basic rating; i.e., an evaluation of the effect of the design approach on each system parameter. Here the effect can either improve the relative status of the parameter or degrade it. Therefore, positive numbers are entered in the DESIR column when a net parameter improvement results. Negative numbers are entered in the UNDESIR column when the parameter is degraded. Scaling from 1 to 100 is a measure of the degree of positive or negative impact on the parameter; e.g., if the reliability degraded 10 percent as a result of a design change, then -10 would be entered in the UNDESIR column across reliability. The scale in Figure 5-5 provides a convenient aid for the selection of numerical values when purely objective calculations cannot be made.

(4) Multiply, add, and average the total rating as follows:
(a) Multiply the values in the "basic rating" column by corresponding values in the "relative weighting" column and enter the product in the appropriate "adjust values" column.
(b) Algebraically add the "adjusted values" to arrive at a "net value" for the design approach.
(c) Add up the weighting factors for this design approach.
(d) Divide the "net value" by the weighting factor total to get an "average net value". The algebraic sign (+ or -) will indicate whether this design approach is desirable. The "average net value" is the figure of merit for each design approach.

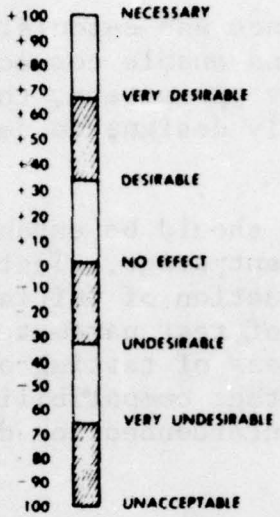


Figure 5-5. Basic Rating Scale

5-15 DESIGN EVALUATION

A design review, properly carried out, provides a means for evaluating equipment compatibility during its design phases. The check-off list, used jointly by designers and compatibility engineers, is another vehicle for evaluating design compatibility and should form a part of the permanent documentation record of the unit in compatibility report files.

The compatibility report, used in conjunction with the design review, is the key vehicle for evaluating compatibility design. The compatibility report should be developed in parallel with the design. Like the design review and the checklist, it is an evaluation tool. It is used to evaluate the compatibility of the design concepts and design techniques with ATE and the adequacy of test points and test parameter definition. It also makes the designer conscious of his responsibilities to design an ATE-compatible unit and gives management an overview of the degree of compatibility being achieved as the design progresses. To be fully effective, the compatibility report should not be exclusively a designer function. It should include a complete test plan comprising stimulus and measurement requirements, diagnostic test strategy, an interface concept, and other pertinent data.

Testing during the development cycle is a fourth vehicle for evaluating compliance to compatibility objectives. Although

analysis based upon experience and calculations may predict the manifestations of failure and enable correct and complete application of test points and test parameters, there is no substitute for performance testing early designs to determine adequacy of their operation.

A planned testing program should be established and executed during the product development stage. Testing activities should consist of engineering evaluation of initial designs for: adequacy of test points, definition of test parameters, effectiveness of fault isolation, effectiveness of testing operational performance, test point isolation, and other compatibility parameters; e.g., human factors, grounding, interconnection devices, adjustments, etc.

Although it is agreed that compatibility cannot be tested into a product, a conscientious testing effort will furnish valuable data for design evaluation and improvement. Also, a well-planned test program will demonstrate that a design has achieved its compatibility objectives. It is recommended that adequate testing be done prior to the final design review so that testing results can form the basis for the final compatibility report and corrections can be implemented prior to the release of hardware designs to production.

The amount of engineering evaluation testing should be sufficient to demonstrate that compatibility has been achieved. The evaluation program should utilize ATE or test equipment and test setups that simulate ATE when ATE is not available. Faults should be inserted and diagnostic test strategy demonstrated. If unique environmental conditions are part of the support environment, testing should be run under equivalent conditions.

One of the most important contributions of engineering evaluation tests is the validation of measurable parameters of the product performance at the unit and subunit levels. It is at this time that factual performance and fault isolation data is accumulated and assessed and the operational test requirements are definitized for the final hardware specifications and for the program design document. The test parameters then become the base of reference to be used in the test program design and operational qualification testing which will follow. Presentation of test data in a usable form is important to its future utility. Test points, test equipment, interconnections, and results in the form of pressure, flow, etc. should all be included in the test record.

5-16 EQUIPMENT SPECIFICATIONS

Equipment specifications take on a new dimension when mechanical, hydraulic and pneumatic equipment is supported by programmed test procedures. Dependence on the specification by the test designer is often greater than that of the equipment designer. All decisions must be anticipated in advance and stored in the ATE computer memory. In order to achieve a high level of test program effectiveness, software and hardware must all work together as one. The equipment specification is an important element.

To achieve overall performance control, detail system and equipment specifications are generally prepared very early in the program and the preparation and subsequent updating of these should be made a part of the contract. In addition to system and equipment performance, detail specifications should cover operating characteristics under all expected environments, compatibility levels, reliability levels, and equipment support.

Most important to programming and compatibility is specification monitoring. In the early stages of a development program, specifications are subject to considerable change. These changes must be incorporated in a timely fashion because software, not to mention production, integration, test, and quality assurance, is dependent on them. Letting specifications slip behind the equipment adds cost, confusion, and delay.

Specifications and specification modifications should be evaluated from a test programming/compatibility standpoint to assure that the requirements are realistic, thorough, and clear in regard to at least the following:

5-16.1 DESIGN CONSIDERATIONS

(1) Compatibility
(2) Maintainability
(3) Performance
(4) Operation
(5) Quantitative Test Requirement factors
    (a) Range
    (b) Drive
    (c) Count
    (d) Cross-over, etc.
(6) Environment
(7) System effectiveness.

5-16.2 TEST CONSIDERATIONS

(1) Quality factors
    (a) Resolution
    (b) Repeatability or precision
    (c) Offset
    (d) Tolerance
    (e) Deviation
    (f) Linearity
    (g) Distortion, etc.
(2) Accept-reject criteria
(3) Dynamic factors
    (a) Measurement parameters
    (b) Stimulus parameters
    (c) UUT signal excitation sequence
(4) Load factors
(5) Grounding.

REFERENCES

1. AMCP 706-134, Engineering Design Handbook, Maintainability Design Guide.

2. MIL-STD-470 Maintainbility Program Requirements.

3. MIL-STD-785 Reliability Program for Systems and Equipment Development and Production.

4. MIL-STD-1388 Logistics Support Analysis

5. MIL-STD-471A Maintainability Verification/Demonstration/ Evaluation.

6. MIL-STD-1309B Definition of Terms or Automatic Electronic Test and Checkout.

7. AMC-TRADOC Material Acquisition Handbook, 1 November 1975 (prepared as a supplement to AR 1000-1).

8. AR 750-43 Test, Measurement, and Diagnostic Equipment.

CHAPTER 6
TECHNICAL MANUAL CONSIDERATIONS

6-1 GENERAL

The information provided to the technician for performance of his duties is of prime significance to the operational readiness and effectiveness of any equipment or weapons system. Information required by a user in the performance of each task must be provided in the most usable and readily accessible form dependent upon the type of task, the user environment and the skill level of the technician or repairman.

Maintenance information requirements are influenced by the test equipment that is to be provided. When Automatic Test Equipment is applied, it assumes varying degrees of the diagnostic decision-making responsibilities. This influences maintenance task requirements and thus impacts the content of the technical manuals. General guidelines for technical manual design are provided in Reference 1. The paragraphs which follow address technical manual considerations as influenced by ATE.

6-2 BASIC ELEMENTS OF INFORMATION TRANSFER

Information transfer can be considered to consist of the following basic elements as illustrated in Figure 6-1.

(1) Content - Content is the "information" which must be transferred to the user - the data or procedures required for accomplishing an operating or maintenance task.

(2) Information Transfer Media - Media is the means by which the content is transferred to the user. Media consists of the basic subelements, format and package. The package is the physical repository for storing and making available the information as required. This can be the familiar book or microform or simple or exotic audio or audio-visual systems. The format is the means for organizing, expressing and portraying the information. The format can be text, graphics, tables, flow charts, etc.

(3) Application - The application is the intended use of the information for a given task on a given commodity at a specific maintenance level.

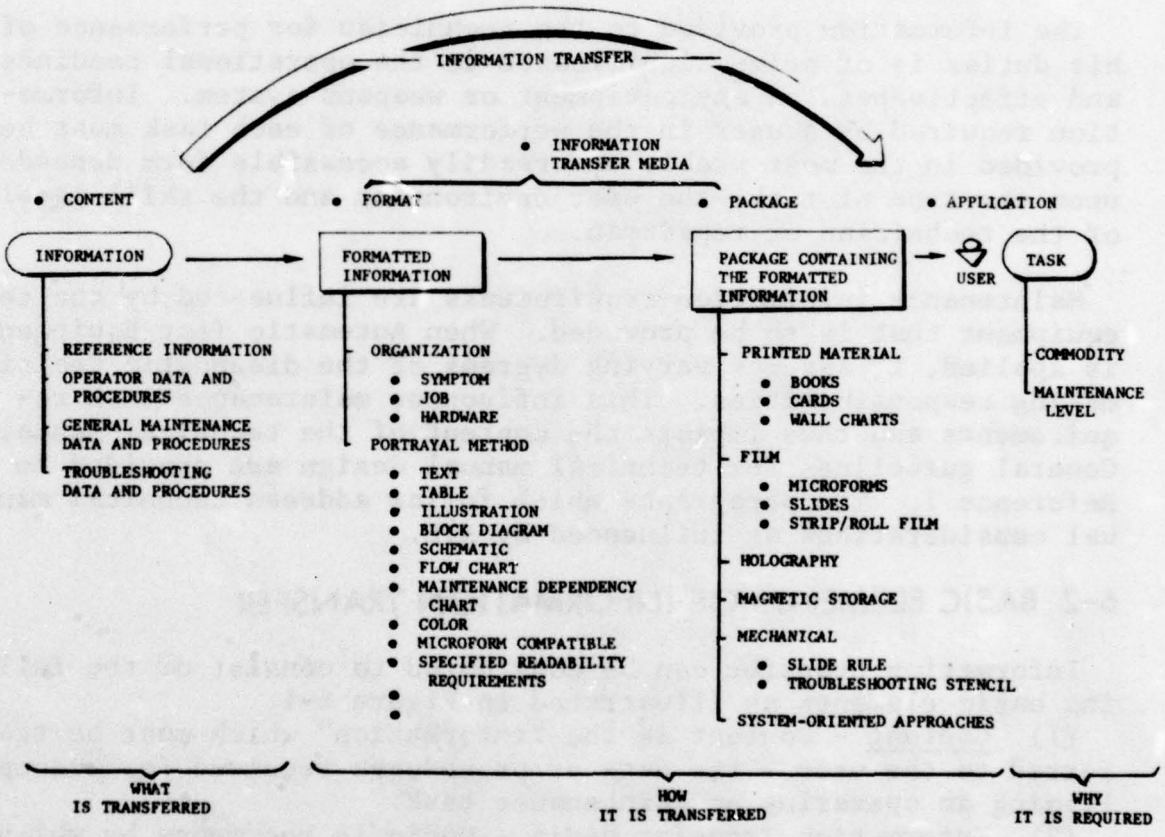


Figure 6-1. The Basic Elements of Information Transfer

Of the basic elements, content is primary. Information must be complete and correct for each application if effectiveness is to be achieved. Format and package are secondary but are important in efficiently conveying the information to the user at a level which he can comprehend.

ATE systems all include some means for communications with the maintenance technician. This can vary from simple Go/No-Go indicators to printers and displays which convey comprehensive maintenance information. Thus the ATE itself can assume part or all of the media responsibility in conveying maintenance information.

6-3 GENERATION OF TECHNICAL MANUALS

In any equipment or weapons systems development and acquisition program, an enormous amount of technical data is generated. This data falls into four overlapping areas:

(1) Engineering Data
(2) Logistics Data
(3) Training Data
(4) Technical Manual Data

The interrelationship of these data areas is shown in Figure 6-2. Note that:

- Not all data is delivered to the Government (and it would be considerably more expensive if it were).
- Not all data is relevant to TMs.
- More significantly, the present definitions of engineering and logistics data are not of themselves sufficient for TMs.

Technical data is expensive and serves needs other than TMs. The optimum balance between performance and life cycle cost can only be achieved by including total technical data planning from equipment concept and formulation through engineering design and development, test and evaluation, production, deployment and operation. Further, technical data procurement lags generation (by at least the format/publication cycle) and therefore the resources allocated for technical data can be (and often are) reallocated to "mainstream" activities.

In defining the technical data that will be required by the operational equipment, it is necessary to recognize the realities outline above. It is also necessary to define the manner in which the technical data is procured. The data must be relevant and current so procedures for insuring this are required.

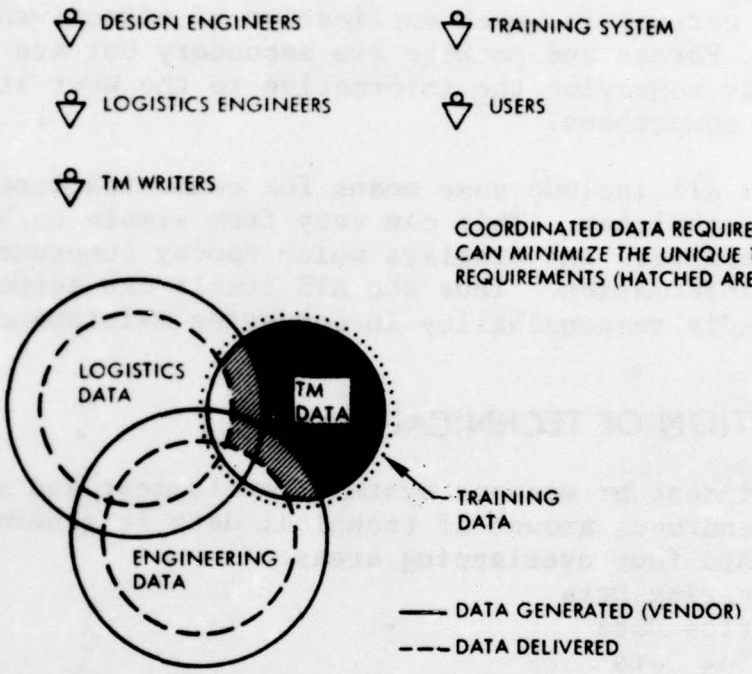


Figure 6-2. Maintenance and Operating Technical Data

The purchase of a coordinated data package which minimizes the unique TM data requirements is an important factor in achieving cost effectiveness. This mandates definition of many support factors early in the acquisition program and before prime equipment design is frozen. Figure 6-3 shows the time phasing of various key activities such as product design, maintainability design, training and support, and it shows how these are related to the technical manual (TM) production activities. The TM activities include:

(1) TM management

(2) TM generation and production including both the product development and test phase and the production and deployment phase

(3) PACKAGE procurement.

Figure 6-4 illustrates a simplified version of the process of generating a technical manual. The figure shows the many elements and activities and their relation to the basic media format and package elements. In particular, it shows two key decisions (that must be made during product design and maintenance analysis) that will effect the choice of media. These decisions are:

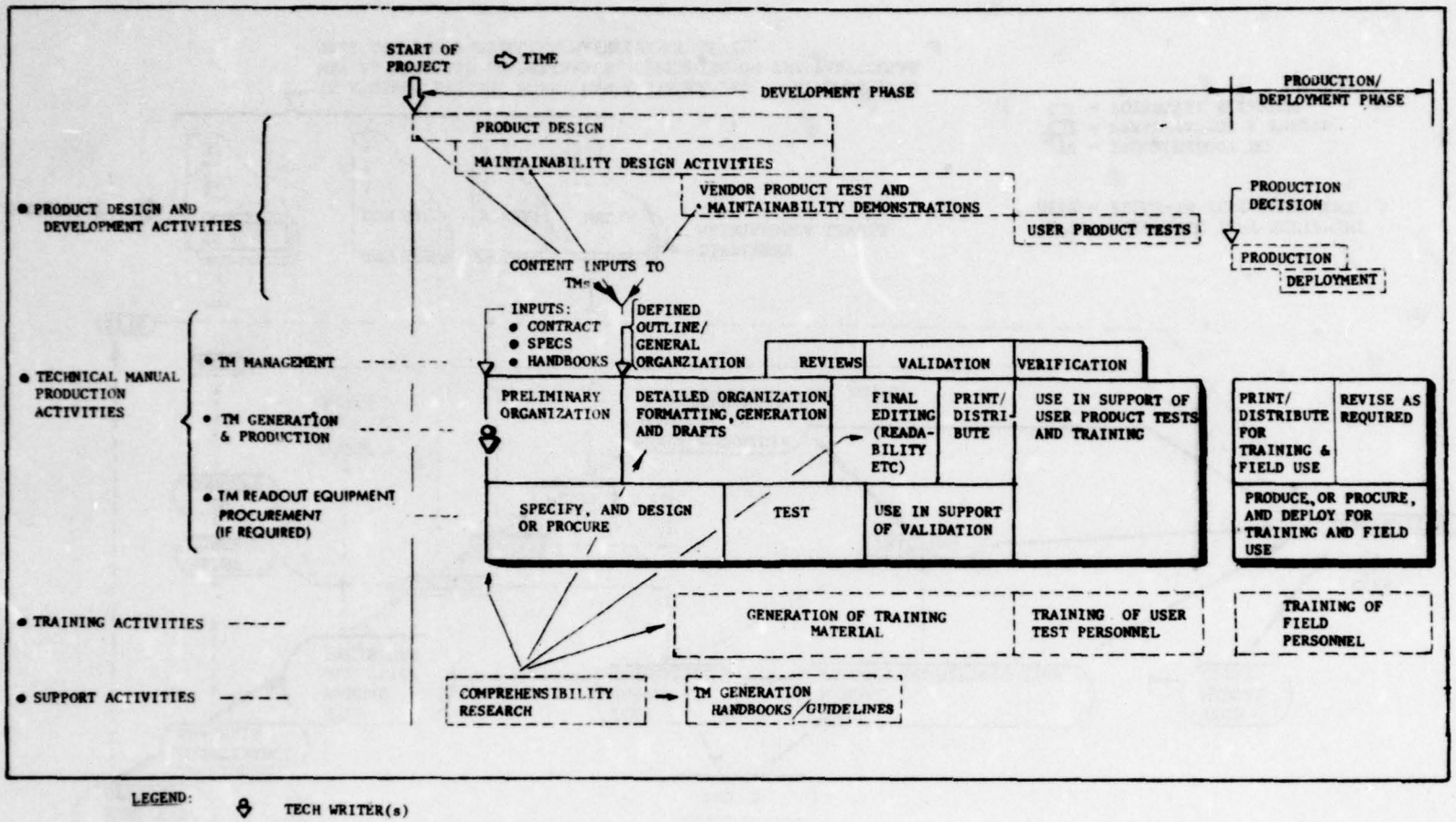


Figure 6-3. Activities and Time-Phasing of Technical Manual Generation

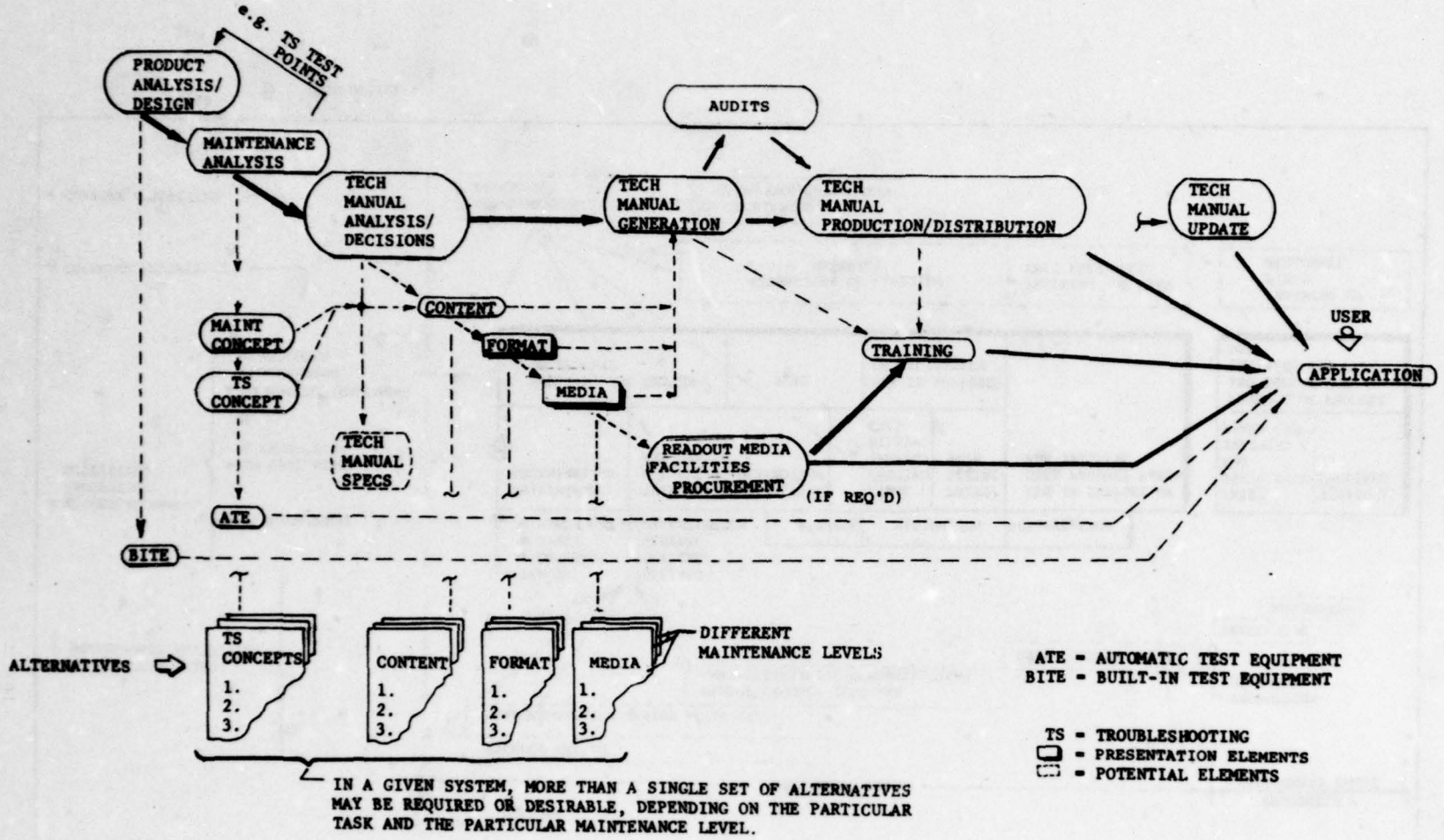


Figure 6-4. Process of Technical Manual Generation

(1) Definition of the Maintenance Concept - The maintenance concept is a comprehensive plan for support of the product at all echelons of maintenance. It includes allocation of maintenance tasks to the echelons of support (Maintenance Allocation Chart (MAC)), inclusion of built-in-test-equipment in the prime hardware (BITE) to aid in checkout and troubleshooting, definition of test equipment to be utilized for each task, and definition of special facilities and fixtures required in each maintenance organization.

(2) Definition of the Troubleshooting Concept - The troubleshooting concept is an outgrowth of the maintenance concept. It is dependent upon the maintenance allocations. The type of support equipment assigned and the packaging concept for the primary hardware. These factors drive the selection of troubleshooting techniques and coupled with maintenance environment are drivers in selecting best applicable media package and format.

Significant points to be made in conjunction with Figures 6-3 and 6-4 are:

(1) Maintenance and support decisions and concepts must be established and developed early enough to influence the design where necessary.

(2) Adequate product "testability" must be provided (in the form of controls, indicators, test points, BITE and/or ATE) to support the troubleshooting concept.

(3) The design and maintenance decisions and concepts form the basis upon which the detailed choice of media can be made.

(4) For a given system or product, there may be more than a single set of alternatives chosen for troubleshooting and for media.

(5) If the media package is to involve hardware (e.g., as for microforms), appropriate procurement actions are required to make this hardware available for the development phase, for training, and for the application phase.

(6) In choosing media, the problem of updating the material must be considered in terms of both format and package. For example, some of the sophisticated formats which provide highly definitive procedures require exhaustive and continuing monitoring of all design changes to determine their impact on the procedures. Generating the necessary changes to impacted procedures could also be a significant task. The means for incorporating such changes into the package is directly dependent on the type of package (e.g., the problem of updating a loose-leaf book is different from that of updating a microform).

(7) The impact of media choices on training must be considered.

(8) The increasing emphasis on technical manuals and the increasing number and complexity of alternative media suggests that a media development specification should be generated for each contract much like the equipment Prime Item Development Specifications of MIL-STD-490.

6-4 CONCEPTS FOR TECHNICAL MANUAL PREPARATION

The major requirements for satisfactory technical manuals are specified in Reference 2 which provides a succinct statement of the many problem areas. Today hundreds of different documented formats exist which are designed to transfer maintenance information and which take different approaches toward this end. The bulk of these approaches are discussed in Reference 3. Four important rules should be adhered to in technical manual preparation.

(1) Completeness and accuracy in manual content is of primary importance - media and format selection is of lesser importance.

(2) Technical manuals should be written around the troubleshooting section with the other sections supporting the troubleshooting section.

(3) Troubleshooting information should be symptom oriented so that the technician can start from the symptom he actually observes.

(4) Troubleshooting information must be in concert with the test equipment which is to be applied (BITE and/or ATE).

6-5 TECHNICAL MANUAL EVOLUTION FACTORS

Changes are presently occurring in Army maintenance policy as reflected in new equipment design and manning and training philosophies. These new directions in maintenance policy are directed toward reducing the range and detail of corrective maintenance burden to the intermediate and depot levels. As ATE and more high reliability prime equipments are introduced into inventory, the amount of detailed technical data that will be required at the organizational level should be reduced. In the foreseeable future, organizational level corrective maintenance data may be limited to that necessary to extend the functions of BITE or ATE subsystems, replacement procedures for defective modules/components identified by BITE or ATE and more detailed fault isolation and corrective maintenance data which might be required to repair a casualty to the BITE and ATE subsystems themselves. Manning and training philosophies are being influenced by shifts in maintenance requirements and evolving work package and job aid concepts. Changes in organizational level skill assignment impact TM reading level requirements. These are all continuously varying

factors which must be considered in defining the technical manual package for support of each new equipment.

REFERENCES

1. AMCP 706-134, Engineering Design Handbook, Maintainability Design Guide.

2. D.A. Ross, Comprehensibility Evaluation of Technical Manuals, WADC Technical Note 59-112, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio 1959 (DDC No. AD 228 235).

3. C.F.Matthews, et al, Study and Proposal for the Improvement of Military Information Transfer Methods, RCA Report CR 75-588-028, 31 July 1975 (Contract No. DAAD05-74-C-0782).

PART III

CONSIDERATIONS FOR GENERAL DESIGN APPLICATIONS

CHAPTER 7
LOGISTIC SUPPORT

7-1 GENERAL

Rapid technological advance has resulted in tremendous demands for logistical support for our complex equipment. These new equipments, although greater in fire power, further compounded the problem because of the need for a flexible, modern-type Army, an Army that must be able to disperse and hide, and converge and fight—an Army that must be able to shoot, scoot and communicate.

Immediately after the United States entered World War II, the great variety and complexity of equipment was such that requirements for repair parts exceeded supply capabilities. Although both Army and contractor-operated schools were established, maintenance men could not be trained fast enough for the task of ultimately maintaining the new equipment pouring from the factories. Under the pressure of designing and producing new equipment, performance was the principal criterion; maintenance was secondary.

7-2 LOGISTICAL OBJECTIVES

Modern army logistics is the process of providing the equipment, supplies, and services, and assuring the continuity of this support, to enable troops to fight under any conditions or in any type of warfare. Modern Army logistics has three key functions—modernization, mobility, and management. This chapter discusses each of these functions. (Reference 1)

7-2.1 MODERNIZATION

This is the process of determining the kinds of items needed to carry out missions to provide the best available designs and

materials to equip troops with new and improved items after they have been accepted for production. In this process of developing and improving new items, improved performance and improved maintenance must go hand in hand. This involves increasing the reliability and maintainability of individual components and of overall systems.

7-2.2 MOBILITY

This is a more elusive element of modern army logistics than modernization because it cannot be easily measured. It involves the responsiveness of support to the combat situation, including the logistic capability to support tactical actions on the atomic weapon battlefield. It is not only the ability to move from one place to another, but also the ability to fight without requiring an uninterrupted flow of heavy logistical tonnage. One measure of mobility is the length of time a unit can move and fight without resupply.

To provide effective mobility, supply austerity is necessary. Some other requisites will be discussed at more length in the paragraphs that follow.

7-2.2.1 What is Mobility?

Mobility is not merely wheels, tracks, wings, and other means of locomotion, but a quality that can be built into items or incorporated into organizations. Mobility is the ability to move or be moved from one location to another and to be logistically supported in response to strategic or tactical requirements. Mobility is particularly important because of the great distances that may be traveled to engage enemy forces, the great mechanized forces of the possible enemy, the necessity to maintain forces capable of engaging that enemy effectively in both nuclear and nonnuclear warfare, and our concept of operations when nuclear weapons might be used. It has three broad aspects—strategical, tactical, and logistical.

7-2.2.2 Absolute Mobility

Modern armies must achieve absolute mobility, and this includes all three aspects of the problem. Strategical mobility means equipment can be readily transported by bulk carriers of the airways, railways, and seaways. To rate high in strategical mobility, the equipment should be compact, lightweight, and designed

to facilitate loading and unloading, including the ability to withstand the shock that may result from air drop.

Tactical mobility means the equipment can move or be moved over all kinds of terrain, including floating on inland waters. This characteristic depends on special military design features such as the capability of survival in the heat, cold, mud, and dust where the Army does its fighting. An important aspect of tactical mobility is the capability of ground vehicles to use a minimum of fuel and many kinds of fuel.

The most important aspect of absolute mobility is logistical mobility. Logistical mobility is another way of saying reliability and maintainability. A vehicle, for example, might be compact and light, it might have an economical, multifuel engine and be capable of crossing the most difficult terrain; but, if it lags behind because of operating failures and cannot be quickly repaired, it has no mobility.

7-2.2.2.1 Mobility and Transportability. The maintainability engineer should take into account during the design period that all U.S. Army weapons, commodities, or systems (not including permanent construction facilities) may have to be moved or transported at some time. This movement or transportation may be from one building to an adjacent building, or around the world.

The maintainability engineer should consult with mobility engineers who are equipped to assist in problems of transport, selection, and adaptation of vehicles and shelters; equipment layout and installations; mounting techniques; shock and vibration reduction; lighting; fire extinguishing; power entrance connections; as well as heating, air conditioning, and ventilation systems for mobile equipments.

Mobile systems generally must be capable of transport over land, sea, and air. The degree of transportability depends on the end use of the equipment. Equipments used within the continental United States have wide latitude for rail and sea transport. Equipments designed for global applications have more stringent weight and size restrictions. For example, in various sections of Europe, railroad tunnels and bridges are built for narrow gage roads. This imposes width and height restrictions greater than those for equipment designed to be used only in the United States.

Detailed requirements and limitations for transportability by vehicle, rail, water, and air are contained in AR 705-8 and AR 705-35. General design considerations for air, rail, and road transportability are presented in the paragraphs which follow.

7-2.2.2.2 Air Transportability. Unless otherwise specified, all weapons commodities or systems should be designed in accordance with MIL-A-8421. In designing for air movement, the transportable item should meet at least the following requirements:

(1) Be of minimum practical weight—item plus container;

(2) Be of minimum practical size—item plus container;

(3) Be capable of being transported by available cargo aircraft; (See Table 7-1 for dimensional and ramp-loading criteria for some Army and Air Force aircraft)

(4) Be capable of withstanding altitude up to 50,000 feet in unpressurized aircraft;

(5) Be capable of withstanding temperature ranges between +165°F. and -67°F.

TABLE 7-1. DIMENSIONAL CRITERIA FOR SOME ARMY AND AIR FORCE AIRCRAFT

		Cargo Compartment (Usable Space)			Loading Aperture		Ramp Data			Cargo Hook Capacity (lb)
	Type	Length	Width	Height	Width	Height	Length	Ground Angle	Floor Angle	
C-130A	Fixed Wing	41'0"	10'0"	9'0"	10'0"	9'0"	10'5"	12.5°	12.5°	(1)
C-130H	Fixed Wing	41'5"	10'3"	9'2-3/4"	10'0"	9'1"	10'3-1/2"	12.5°	12.5°	(1)
C-133A	Fixed Wing	81'10"	11'10"	11'2"	(4)	12'0"	15'9"	9°(2)	9°	(1)
C5A	Fixed Wing	121'1"	19'0"	13'6"	19'0"	12"10-3/4"	23'6"			(1)
C9A	Fixed Wing	55'9"	10'1"	6'9"	11'4"	6'9"				(1)
C141	Fixed Wing	144'7"	19'0"	13'6"	19'0"	12'10-3/4"				(1)
CH47C	VTOL	30'2"	7'6"	8'3"	7'7"	6'6"	(1)	(1)	(1)	28,000
CH54B	Helicopter	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	30,000

Notes:

(1) Not applicable
(2) Ramp toe incline 15°
(3) Straight in loading
(4) Tapers from 9'4" at top to 12'1" at bottom

7-2.2.2.3 Rail Transportability. Equipment to be shipped by rail should not exceed the following:

(1) 124-inch width or 72-inch height in the shipping configuration;

(2) 80,000 pounds for transport on a standard 40-foot flatcar;

(3) The standard railroad clearances as defined in the Berne International Outline.

7-2.2.2.4 Road Transportability. Equipment normally to be shipped by road should conform to the following:

(1) Be designed to meet the mobility requirements set forth in MIL-M-8090 (ASG);

(2) Not exceed 78,000 pounds gross weight, including the supporting vehicle;

(3) Not exceed axle loads of 18,000 pounds, and be limited to 16,000 pounds if the axles are less than 7.5 feet apart.

7-2.2.2.5 Inclination, Shock, and Vibration. All equipment should be capable of withstanding the general inclination and shock requirements specified in MIL-S-901, and the general Type I vibration requirements specified in MIL-STD-167. In addition, equipment should be packaged to withstand the shock and vibration criteria set forth in Table 7-2.

TABLE 7-2. GENERAL TRANSPORTATION SHOCK AND VIBRATION CRITERIA

Shock			Vibration	
Source of Shock	Acceleration (g's)	Duration (ms)	Frequency (cps)	Double Amplitude
Truck	8	5 to 40	2 to 27	±1.3 g's
Rail	30 (bumping shock)	4 to 80	27 to 52	0.036 in.
Aircraft	5.5 (vertical) 1.5 (lateral) 0.8 (longitudinal)	10 to 30 10 to 30 10 to 30	52 to 500	±5 g's
Handling	30	15		
Drop (packaged units only)	24 in. drop on concrete			

7-2.3 MANAGEMENT

The task of maintenance for the Army, with its critical relationship to operational readiness, is one of dealing with technical complexity, broadened by infinite variety, further multiplied by a fantastic range of environmental and mission requirements. The maintenance manager is faced by a highly dispersed Army—posed at combat ready—complicated by the vast distance and channels of communication through which a feedback of vital use-experience and performance data must be retrieved, evaluated, and acted upon. Some of the goals of this vast effort are to:

(1) Assure that the Army's priority combat equipment is ready.

(2) Give combat support that will result in maximum combat effectiveness.

(3) Organize effort in support of combat force needs.

(4) Assure economy of effort.

7-3 THE ARMY MATERIAL LIFE CYCLE

To provide guidance for the maintenance engineer and enable him to design for support, particular design configurations must be considered which will result in the most desirable logistical support policy with due consideration to the impact on the Army in terms of combat readiness, availability, mean-time-between-failures, storage, transportation, mobility, etc. Figure 7-1 illustrates the Army Materiel Life Cycle to familiarize the maintenance engineer with the phases and development decision points of equipment development and production.

Shown left to right are the four phases of a major equipment program as they are accomplished in time: conceptual, validation, full scale development and full scale production.

During the Conceptual Phase, threat projections, technological forecasts and Joint Service and Army Plans are examined by the combat developer to determine operational capabilities, doctrine, organization, or potential materiel systems that will improve Army forces. The technical, military and economic basis for proposed systems are established and concept formulation initiated through pertinent studies and by the development and evaluation of experimental hardware by the materiel developer. Critical technical issues, operational issues, and logistical support problems are identified for resolution in subsequent phases in order to minimize future developmental risks.

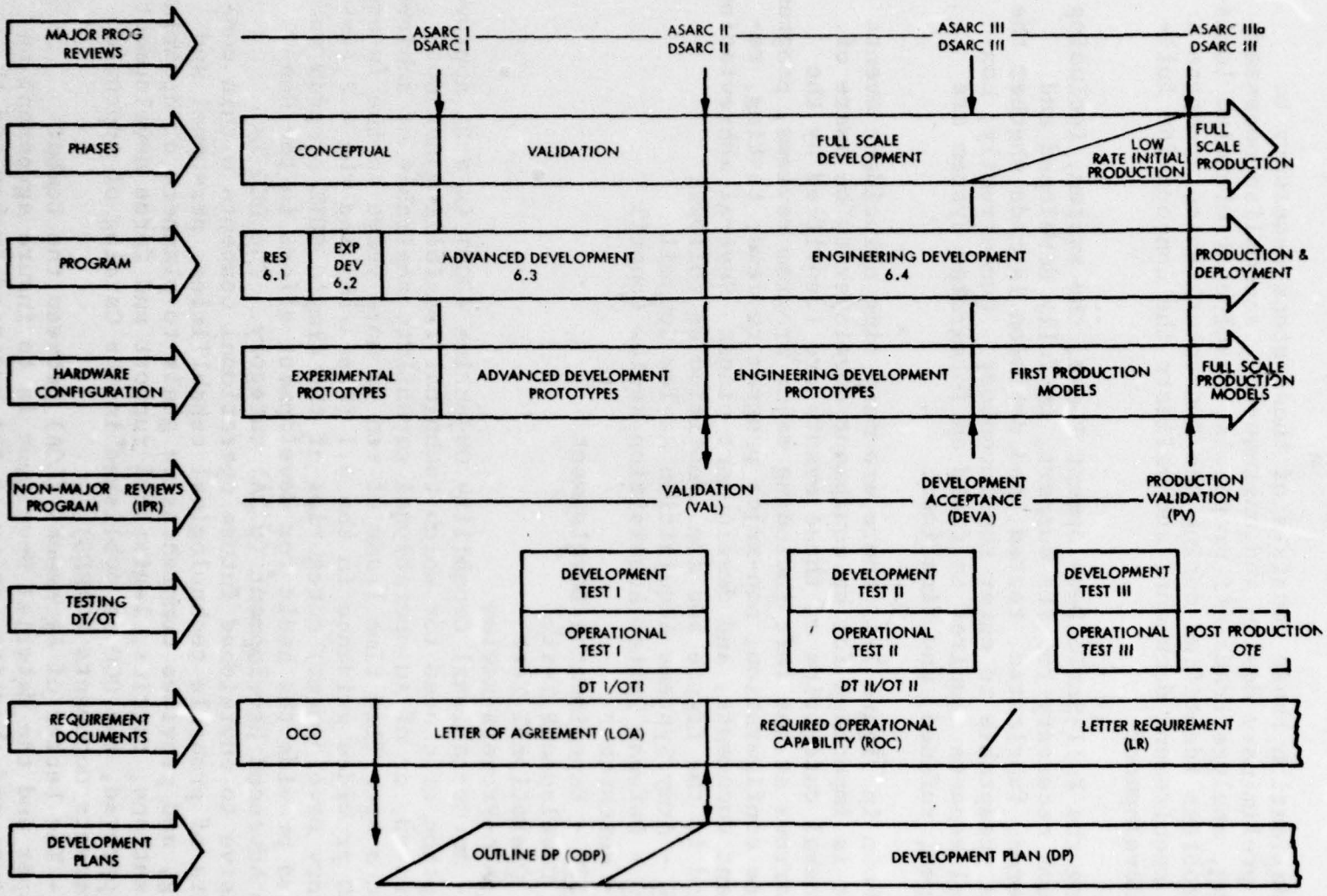


Figure 7-1. Army Materiel Life Cycle

The Validation Phase consists of those steps necessary to verify preliminary design and engineering, accomplish necessary planning, analyze trade-off proposals, resolve or minimize logistics problems identified during the Conceptual Phase, prepare a formal requirement document, and validate the concept for full-scale development.

During the Full-Scale Development Phase, the system, including all items necessary for its support, is fully developed and engineered, fabricated, tested, and decision is made whether the item is acceptable to enter the inventory. Concurrently, non-materiel aspects required to field an integrated system are developed, refined, and finalized.

As shown in Figure 7-1, there are many time coincident events that it is important for an equipment developer to be aware of. The general categories of these events are identified by the large arrows at the left including major program reviews, program, hardware configuration, non-major program reviews, testing, requirement documents, and development plans. Several abbreviations are used in the figure and are identified as follows:

ASARC - Army Systems Acquisition Review Council
DSARC - Defense System Acquisition Review Council
RES - Research
EXP DEV - Experimental Development
DT - Development Test
OT - Operational Test
IPR - In-Process Review

OCO - An Operational Capability Objective (OCO) is a DA approved description of a need for which technical feasibility has not been proven, or of an operational capability desirable of achievement in a specified time frame of ten or more years in the future. The OCO provides guidance in the 6.1 (Research) and the 6.2 (Exploratory Development) categories of the Army's RDTE program and may also provide the basis for development effort in the Non-system Advanced Development (6.3A) category. The OCO is responsive to envisioned future operational concepts within constraints of probable technological capabilities, personnel and funding, and provides comprehensive goals to planners of doctrine, organizations, tactics, logistical support and force development. When approved, the OCO is published in the Catalog of Approved Requirements Documents (CARDS).

LOA - The Letter of Agreement (LOA) between the Combat Developer and the Materiel Developer is to insure agreement on the nature and characteristics of the proposed system and the investigations needed to develop and validate the system concept,

to define the associated operational, technical and logistical support concepts and to promote synchronous interaction between the combat developer and materiel developer. The LOA is the document of record to support effort in the System Advanced Development (6.3B) category of the RDTE program which includes development of the Concept Formulation Package (CFP). An LOA may also support Nonsystem Advanced Development (6.3A) category of the RDTE program if conceptual application to improved or new materiel systems can be adequately defined.

ODP - An Outline Development Plan (ODP) is a document of record, prepared by the materiel developer in coordination with the combat developer to support the materiel system concept.

The ODP is a definitive plan for management of the advanced development effort to achieve the Materiel Objective addressed by the Letter of Agreement (LOA). In addition, the ODP provides appropriate analysis of technical options and plans for development phase of RDTE program prior to initiation of a firm requirement via a Required Operational Capability (ROC) document or a Letter Requirement (LR). The information contained in the ODP will reflect the best available data and will clearly delineate that these are best estimates, subject to major changes as the system approach is developed.

ROC - The Required Operational Capability is a clear and concise statement of the essential operational, technical, logistical and cost information essential to initiate full-scale development or procurement of a materiel system. The ROC supports RDTE programs for combat development and non-combat development programs in Engineering Development (6.4) and Operational Systems Development (6.7). A formal requirement stated in the ROC, with its implicit commitment to an eventual production decision, normally will not be established until a thorough advanced development program has been conducted under an LOA which results in an up-to-date Concept Formulation Package (CFP) or procurement of a nondevelopmental item has been determined to be desirable. The advanced development program will include testing of components and/or prototypes to demonstrate adequately both its technical feasibility and operational feasibility.

As a general rule, a ROC is not required for full-scale development and/or procurement of a system for which there is another valid, approved requirement document.

DP - A Development Plan (DP) is a document of record, prepared by the materiel developer (usually AMC) in coordination with the combat developer to serve as the basic management document for all Army materiel acquisition programs supported by an approved materiel requirement, i.e., ROC or LR. The DP provides

appropriate analyses of technical options, life cycle costs, plans for development, testing, production training support and logistic support.

LR - The Letter Requirement (LR) is negotiated between the Combat Developer and the Materiel Developer. The LR constitutes the requirement of record to support low risk full-scale development (6.4) and procurement. LR provides an abbreviated procedure for acquisition of low value items and will be used in lieu of the ROC when applicable. Low value items are low unit cost, low risk developmental or commercial items for which the total RDTE expenditures will not exceed $1 million, and the procurement costs will not exceed $2 million for any one fiscal year or $10 million for the five year program period. (1976 figures)

7-4 DESIGN-TO-COST

Design-to-cost is a system/equipment design process utilizing unit cost goals as thresholds for managers and as design parameters for engineers. In July 1971, DoD Directive 5000.1* was issued establishing the design-to-cost policy. This document stated in part:

> "Cost parameters shall be established which consider the cost of acquisition and ownership; discrete cost elements (e.g., Unit Production Cost, Operating and Support Cost) shall be translated into 'design to' requirements."

Design-to-cost represents a major shift in philosophy from past research and development priorities of performance first, schedule second, and cost third. Production and support costs now receive equal priority with performance (at least conceptually). Tradeoffs between cost, schedule, and performance aimed at providing the Government with optimum capability within projected program costs are encouraged.

The design-to-cost target is a Government established cost goal introduced into the initial development contract. This introduction is for the purpose of directing the contractor's attention to production and ownership costs as he develops his concept and design. The contractor's design is measured against the design-to-cost goal throughout all contract negotiations and also during the entire span of contract performance. At any point, the

*Department of Defense, Acquisition of Major Defense Systems, DoD Directive 5000.1, 13 July 1971

failure of the contractor to develop a system/equipment that achieves the design-to-cost goal could result in cancellation of the contract, termination of the program or possible a reduction in the contractor's fee or profit. On the other hand, to achieve or beat the design-to-cost goal would normally result in an increased fee for the contractor.

Although it is desirable to have total life cycle costs as a design parameter, the current practice is to focus on the cost of production hardware. The shift from "design to life cycle costs" to "design to production costs" is a practical one that reflects such factors as poor data collection systems for operating and support costs, the inadequacy of a feedback mechanism from the field to designers, and the lack of contractural procedures for enforcing operating cost requirements.

The emphasis on "design-to-unit production cost" must not be construed to imply that the life cycle cost is not important in systems/equipments acquisition. The Joint Design-to-Cost Guide (Reference 2) specifically states that: "Acquisition cost reductions must not be achieved at the expense of increased ownership costs or through the sacrifice of performance essential for mission accomplishment. The DoD shall continue to strive toward refining ownership costs to a degree equal with acquisition cost."

7-4.1 LIFE CYCLE COST CONSIDERATIONS (REFERENCE 3)

It is widely recognized in principle that current cost pressures dictate a total cost approach (development, production, operating and support). This is particularly essential in some areas where visible support costs range from three to ten times the acquisition cost over a ten-year life span.

A number of reasons frequently make the life cycle cost approach difficult in practice. Better DoD cost accounting methods are needed to associate major costs of operations and support with specific systems. These are currently being implemented. In terms of contractual relationships, DoD is looking at ways to hold contractors more responsible for maintenance and operating costs.

If a life cycle cost approach is not practical, the closest approximation possible should be used. A number of early applications of design to cost have established firm commitments on unit production cost and on reliability and maintainability which can be controlled and measured to a significant extent during the

development and early operational phases. Several major defense system and subsystem programs are using predicted life cycle cost as a primary source selection criteria. It is entirely feasible to conduct a design competition which will include as a source selection factor the lowest life cycle cost, using definitions and models provided by the Government. It is then desirable for the Government to structure tradeoffs within the limits of unit production cost bands.

7-4.2 CHARACTERISTIC FEATURES

In October 1973, the Joint Logistic Commanders published a Joint Design to Cost Guide to provide information and guidance to their commands. (Reference 2) The Deputy Secretary of Defense, in March 1974, stated in a memorandum to the Secretaries of the military departments that he considered the guide an excellent document and endorsed fully the thrust it conveys. The Joint Design to Cost Guide provides guidance for design to cost efforts. A full-scale design to cost effort begins with the requirements process. At this stage, production costs, key support cost factors and quantity relationships are derived, compared with "available" resources, and iterated as primary parameters during the formulation of minimum essential performance requirements for the new system or equipment. Such cost-quantity relationships are approved by a designated authority prior to advanced development. These actions establish cost goals which can be validated and refined for use as primary design parameters, equal to performance in priority, during full-scale development.

As the program progresses through advanced and full-scale development, some cost (production and support) and performance tradeoff flexibility is needed to permit development of an acceptable system within the cost constraints. For this purpose, design to cost programs feature these characteristics:

- Use of end-item minimum performance goals or specifications (to allow tradeoff flexibility) rather than detailed design specifications for systems, subsystems and components.
- Tradeoff decision thresholds for program managers and other acquisition managers will be established to clarify their authority to make tradeoffs within the overall cost, schedule, and performance requirements of the program.
- Consideration of personnel and training cost factors early in the acquisition process to influence the design tradeoffs.
- Techniques determined in advance for the translation of constant fiscal year dollar design to cost goals into current and then-year dollar values (for the specified quantities and other quantities at the specified production rate or variations thereof).

- Separation of mandatory versus desirable system performance characteristics, and identifying characteristics of marginal cost effectiveness to make the most appropriate tradeoffs to attain cost goals.
- Periodic and timely feedback of estimated production, operating, and support costs, or approximations, to permit early corrective action in high risk and problem areas of the system design.
- Timely introduction of all engineering requirements and design considerations so later more costly engineering changes are avoided.
- Appropriate use of standardization concepts.
- Use of producibility and value engineering techniques, particularly in areas of high cost, early in the development.
- Structuring the contract to permit maximum tradeoff flexibility between cost, performance and schedule.
- Devoting sufficient development time and resources to iterate designs to reduce future costs.
- Maintaining competition among contractors and/or alternative systems as long as economically justifiable.
- Consideration of the use of contract incentives during development and production which motivate the contractor to strive toward lower production and/or support costs.
- Consideration of contractor maintenance or warranties for use during the early part of the production and deployment phases of the acquisition process.
- Periodic top management review to determine whether or not to continue, alter or cancel the program, based upon progress in achieving the design to cost goal and related performance goals.

The foregoing are characteristics of a defense system program developed under ideal conditions and may, of necessity, be modified in real-world situations. The degree of application of these features will vary not only from program to program, but also from phase to phase within a given program. Figure 7-2 highlights some of the major considerations in a hypothetical design to cost program.

7-4.3 DESIGN-TO-COST APPLICATIONS

It is the intention of DoD to apply design to cost principles and concepts to all major defense system programs, as well as to most smaller programs and subsystems. In meaningful application of design to cost, the key considerations are applied with careful selectivity and variation in intensity, depending upon the

Hypothetical Design to Cost Program			
Factor	Concept and Validation Phase	Full-Scale Development Phase	Production Phase
Specification and Request for Proposal	Limited number of critical performance characteristics. Additional goals or features in terms of priorities.	Minimum performance features—no "how to" specifications.	Minimum use of military specifications.
Cost goal	Variable (but defined) budgetary estimate.	Increasingly firm cost. Possible production price option.	Firm cost.
Cost goal (support)	Life cycle cost or approximation (reliability and maintainability). Life cycle cost may be source selection criterion.	Same as concept and validation, but firmer base.	Perhaps warranty.
Contract	Cost type.	Cost type with possible production options.	Fixed price.
Incentives	Performance, reliability, maintainability, life cycle cost and in some cases production unit cost.	Production unit cost; life cycle cost or approximation (reliability and maintainability), performance.	Profit. Production unit cost goal. Possible maintenance warranty. Value engineering.

Figure 7-2. Design-To-Cost Considerations

scope and characteristics of the individual program and recognizing the need for a "tailor made" approach to each situation.

Two specific types of application are frequently questioned. The first type is application to a system program of such overriding importance to national defense that performance or schedule tradeoffs are not feasible if the threat is to be met. However, even in these cases, application of a number of design to cost characteristics should help achieve the desired capability at less cost than possible under past practices. Nevertheless, the highest priority of performance or schedule will probably dominate cost in such important systems.

The second type of application frequently questioned is the "one of a kind" situation. In this case, the development cost may tend to be a very large part of the total acquisition cost. There may, therefore, be more emphasis on development cost in source selection and evaluation. However, even for these cases, there may be areas of commonality in parts of the "one of a kind" system which repeatedly use similar technology. These areas can be usefully controlled from the design to cost viewpoint. It may, for example, be useful to specify minimum performance of subsystems and components at a particular cost. Thus, the "one of a kind" situation deserves careful study to determine just how design to cost can be employed at the subsystem or component level.

7-4.4 RELATIONSHIP TO DOD DECISION PROCESS

Among the decision-making steps which are now being taken within the Office of the Secretary of Defense are:

- DSARC review of system cost goals, at each stage of the development process, includes the analysis of "affordability" and quantity/quality trades. This action also results in a decision on the recommended cost goals and the completed cost and performance tradeoffs.
- System unit production and life cycle cost estimates, reliability and maintainability goals and other support requirements are independently estimated and reviewed during each phase of the acquisition process.
- Specific attention is given to the prototype approach and the test and evaluation methods to verify performance, reliability, producibility, maintainability and refinement of cost estimates.

7-5 THE ARMY MAINTENANCE MANAGEMENT SYSTEM

The Army Maintenance Management System (TAMMS) has been engineered to promote maximum materiel readiness by increasing equipment reliability and maintainability and improving logistical support. The system (Figure 7-3 is designed to answer the following questions:

(1) What is the unit materiel readiness?
(2) Is the army maintenance system effective?
(3) What are the maintenance resource requirements?
(4) Does equipment meet the reliability criteria?
(5) Does equipment meet the maintainability criteria?
(6) What is the equipment density by unit, type, model, series, and class?
(7) What is equipment service life?
(8) Are modification work orders applied? Is there a plan for efficient application of work orders?

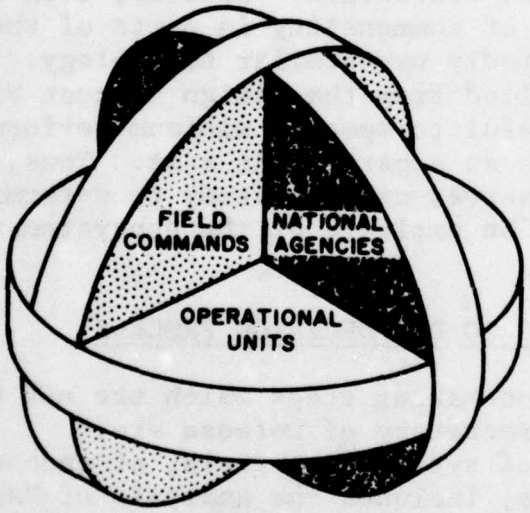


Figure 7-3. TAMMS—The Army Maintenance Management System

7-5.1 TAMMS RECORDS

TAMMS policies and procedures are contained in the following Department of the Army publications:

TM 38-750, The Army Maintenance Management System (TAMMS). The basic manual in the TAMMS system, this TM provides equipment record procedures to be used for control of operation and maintenance of all Army equipment.

TM 38-750-1, The Army Maintenance Management System (TAMMS) Field Command Procedures: Details the Field Command Procedures for processing the maintenance data recorded by TAMMS into usable maintenance information at the organizational, support, and installation levels.

TM 38-750-2, The Army Maintenance Management System (TAMMS) National Agency Procedures: Describes the National Agency Procedures for processing the data generated by TAMMS into usable information, for maintainability engineering supply management, research and development procurement, production, and quality assurance.

TAMMS records are used for controlling the operation and maintenance of all Army materiel covered by this manual. The procedures in TAMMS are in accordance with the policies established by AR 750-1.

TAMMS procedures apply to all Department of the Army units, organizations, and activities. Application is universal to all Army equipment within the Department of the Army except:

(1) Repairs and utilities (R&U) installed equipment.

(2) Industrial production equipment.

(3) Locally purchased non-Federal stock numbered, nonstandard (nontype classified) equipment, other than commercial vehicles and test and measuring equipment.

(4) Equipment procured with nonappropriated funds.

The procedures for the use, preparation, and disposition of forms and records of TAMMS are applicable to:

(1) Army equipment in support of effective materiel readiness. (AR 95-33)

(2) Equipment improvement reporting.

(3) Recording and mandatory reporting of all modification work order requirements and accomplishments.

(4) Recording essential information to be used for evaluation of materiel readiness.

(5) Recording and reporting of engineering data for use in the design of new equipment, redesign of standard equipment, and product improvement.

(6) The collection of inventory, operational and maintenance data on special one-time studies or projects. In cases where the forms and procedures do not fully meet the requirements of such studies, approval for deviation must be obtained from Headquarters, Department of the Army.

(7) The periodic application by the Department of the Army of a sampling technique to obtain specific maintenance action data from selected units located in a specific geographic area. This sampling will include only a designated quantity of a specific type, model, or series of equipments for a limited time period (AR 750-37).

(8) Recording and reporting maintenance float actions on DA Form 2407 in accordance with AR 750-1.

TAMMS records cover equipment operational, maintenance, and historical records, including records and procedures for calibration and ammunition.

(1) Operational Records. These records provide the means for control of operators and equipment, operational planning and optimum use of equipment.

(2) Maintenance Records. These records are established to control maintenance scheduling, inspection procedures, and repair workloads. They provide a uniform method for recording corrective action taken by responsible maintenance elements. These records are used in determining the current status of equipment readiness, reliability of equipment utilization, and logistic requirements. Certain records are designed to permit analysis of causes of equipment failure and mortality rates of components.

(3) Equipment Historical Records. Equipment logs prescribed in this manual are the historical records for individual items of Army equipment. They are the permanent record of information pertaining to the receipt, operation, maintenance, modification, transfer, and disposal of equipment.

(4) Ammunition Records. Munition records and procedures are prescribed to control and report munitions. Procedures for nuclear weapon reporting are contained in (C) TB 9-1100-803-15.

(5) Calibration Records. Calibration records and procedures are prescribed for the control of this function for Army equipment.

The Commodity Commands obtain these maintenance data from one central point—a data bank contained at the Maintenance Management Center at Lexington, Kentucky 40507.

7-5.2 SAMPLE DATA COLLECTION (SDC)

SDC is a procedure provided under AR 750-37 for the collection of maintenance data. It utilizes sampling techniques to collect data on specific selected items, in specific selected units, for a specific period of time. Sample data collection, although it

does constitute some additional workload on the reporting units involved, is still considerably less than the total data collection under TAMMS (The Army Maintenance Management System). With SDC, a minimum number of reporting units are selected. The data is more reliable, since with a small sample and specific units involved, the data collection supervision can be concentrated; closer editing of forms is accomplished by data collectors at the reporting unit to assure that all data is reported accurately. The amount of data received from SDC is far less than that submitted under TAMMS and therefore far fewer resources are required.

7-5.2.1 SDC Collection Methods

Three collection methods of SDC are in common use today, free flow, semi-controlled and controlled.

The free flow method is troop operated and managed. This method is the same method that was used under TAERS (The Army Equipment Record System) and still is used under TAMMS. The user in the field fills out the forms and submits them directly to the national level. (Only standard TAMMS forms are authorized.) Limited modification to the standard TAMMS forms is authorized.

The semi-controlled method is the one most widely used with SDC. This method is where the user fills out the form and a technical assistance representative of the commodity command reviews, edits, collects, and forwards it to the national level. (Only standard TAMMS forms authorized.) Limited modification to the standard TAMMS forms is authorized.

The controlled method of data collection, while probably the most desirable, is the most expensive. (The expense involved stems from the quantity of personnel required to be present to record the data. For example, in one Battalion, five data recorders would be required. (one at the Bn shop and one at each of the four company shops.)) It utilizes the commodity command personnel to record and collect the data with no requirements placed on field personnel. This method is used when the type of data required is that which would not normally be generated and recorded by troops in the field. This method of collection permits the design and use of special data collection forms.

7-5.2.2 SDC Summary Reports

Four summary reports are available in SDC programs as authorized by DA Circular 750-37-30, identified by Part names A through D:

Part A - Logistic Management Monthly Summary
Part B - Logistic Management Analysis Quarterly Summary
Part C - Logistic Management Quarterly Summary
Part D - Logistic Management Analysis Report

Part A is a monthly summary and is optional at the discretion of the commodity command. Normally, it will not be produced because of the small span of data. Part B is the detailed Analysis Quarterly Summary. It may be prepared by the commodity command or by AMMC for the commodity commands. Part C is a summary of the detailed information in Part B. It is designed for use by commanders and managers at the executive level and portrays the information both numerically and graphically. Part C is produced by AMMC. Distribution of this summary is made to all interested agencies and activities and includes SDC participating units. Part B, when SDC is used for ground vehicles, generally contains a discussion of maintenance summaries, action code summaries, usage distributions (miles and hours), scheduled and unscheduled maintenance summaries, OR (Operational Readiness) trend charts, cost parameters, replacement part summaries, maintenance ratio charts and mean time between maintenance requirements. Part C contains usage characteristics, readiness characteristics, maintainability characteristics, reliability characteristics and cost characteristics. Most of the characteristic data is provided in chart form for easy reading as is illustrated by a usage chart and an OR trend chart shown in Figures 7-4 and 7-5 respectively. In general, Part C is chart oriented while Part B is computer summary listing oriented.

7-6 LOGISTICAL FUNCTIONS AND MAINTENANCE SUPPORT PLANNING

At the present time, weapon systems and related equipment are generally mass produced and distributed worldwide for use in varying environments. The degree to which the weapon system succeeds or fails depends on the measure of care exercised in discharging the following eight logistical functions:

(1) Research and development.
(2) Standards and specifications.
(3) Purchase and inspection.
(4) Identification and cataloging.
(5) Requirements and funding.
(6) Supply and stock control.

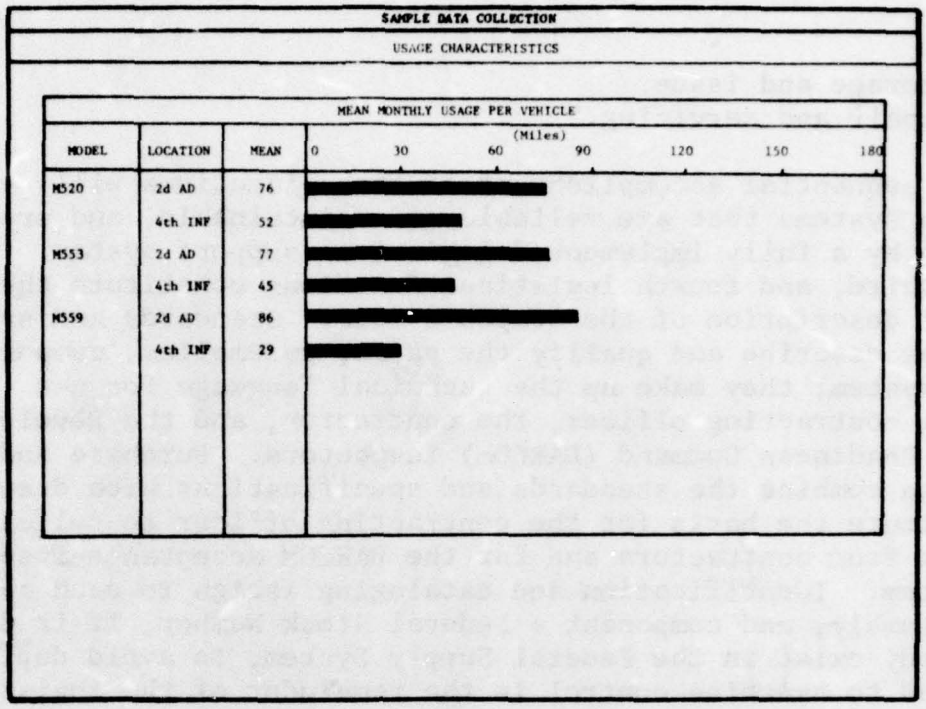


Figure 7-4. SDC Usage Characteristics (Miles/Month)

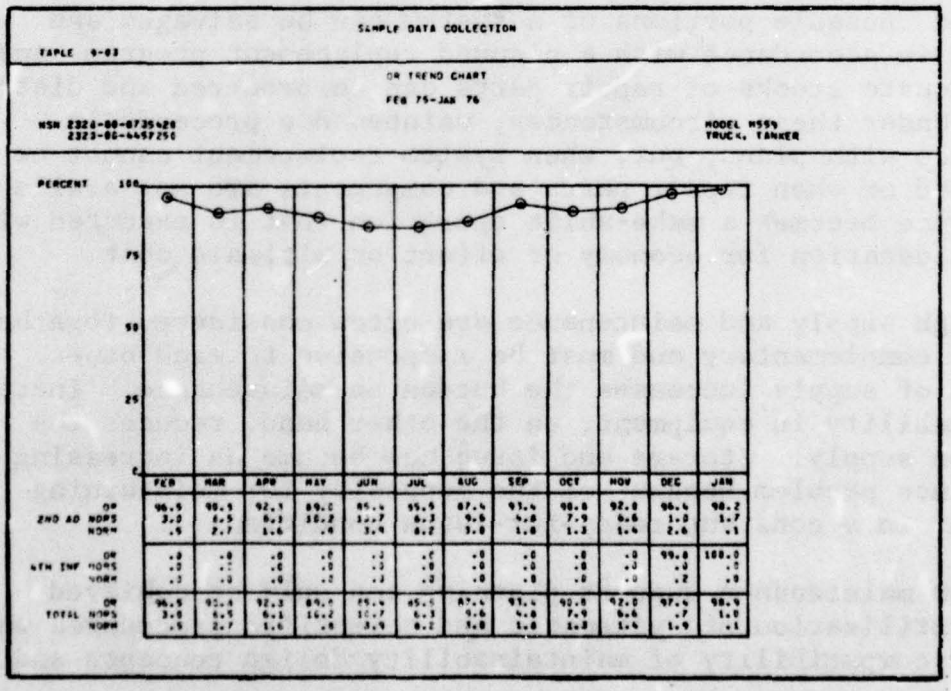


Figure 7-5. SDC Operational Readiness Trend Chart

(7) Storage and issue.
(8) Repair and servicing.

Proper sequential accomplishment of these functions will result in weapon systems that are reliable and maintainable, and are backed up by a fully implemented logistical support system. The second, third, and fourth logistical functions constitute the technical description of the weapon system. Standards and specifications describe and qualify the parts, assemblies, components, and the system; they make up the technical language for use among the contracting officer, the contractor, and the Development and Readiness Command (DARCOM) inspectors. Purchase and inspection combine the standards and specifications with drawings to constitute the basis for the contracting officer to solicit proposals from contractors and for the DARCOM acceptance-inspection system. Identification and cataloging assign to each repair part, assembly, and component a Federal Stock Number, if it does not already exist in the Federal Supply System, to avoid duplication and to exercise control in the remainder of the logistical functions.

The fifth, sixth, and seventh logistical functions are important parts of the entire logistical support system. Quantitative requirements, combined with adequate funds, indicate that marginal and unusable portions of a system can be salvaged and replaced in accordance with a planned replacement program, and that adequate stocks of repair parts can be procured and distributed. Under these circumstances, maintenance proceeds in accordance with plans, but, when system replacement cannot be programmed or when repair parts and components are not available, maintenance becomes a make-shift operation that is executed without consideration for economy of effort or ultimate cost.

Although supply and maintenance are often considered together, they are complementary and must be responsive to each other. A shortage of supply increases the burden on maintenance. Increased maintainability in equipment, on the other hand, reduces the demand on supply. Storage and issue has become an increasing maintenance problem because of the necessity for maintaining equipment in a constant ready-for-issue condition.

Optimum maintenance support planning can only be achieved through utilization of systematic and scientific procedures which consider compatibility of maintainability design concepts and

policies contingent on decisions arrived at by analysis of maintenance support formulas. The following paragraphs present in detail the application of quantitative techniques in the development of maintenance support plans.

7-7 INTEGRATED LOGISTIC SUPPORT (ILS)

7-7.1 IMPLEMENTATION GUIDANCE

The Integrated Logistic Support Implementation Guide for DoD Systems Equipment (Reference 4) is the basic document used by the Army for detailed guidance concerning ILS interfaces, typical logistics support, analysis process and quantitative methods and techniques for use in developing ILS requirements.

During the early stages of the acquisition cycle the system/equipment data is in general, parametric or outlined. As the design progresses and the product baseline is identified, logistic support requirements are determined in increasing detail.

7-7.2 PRINCIPAL INTERACTION

Interaction between logistic support and design engineering activities are many, varied and continuing, particularly in the early phases of a system/equipment acquisition program. Logistic feasibility studies are made concurrently with, and closely correlated with technical feasibility studies. A continuous dialogue is maintained between engineer and logistician as an inherent part of system development. Logistic Support Analysis (LSA) efforts during the program initiation phase are of special importance because they have the potential for major impacts on design, reliability centered maintenance, system supportability and life cycle cost before the baseline design has been established.

7-7.3 PROGRAM ESSENTIALS

The level of detail of the analysis and the support system design effort in the ILS program is tailored to each system/equipment procurement. Program essentials are:

(1) The analysis and definition of qualitative and quantitative logistical support requirements.

(2) The prediction of logistic support costs in funds and other resources.

(3) Evaluations and tradeoffs.

7-7.4 THE LOGISTIC SUPPORT ANALYSIS (LSA)

In general, the LSA process (MIL-STD-1388) is a systematic, comprehensive analysis including the projected service environment of the system/equipment performed on an iterative basis throughout the acquisition cycle. The LSA is the single analytical logistic effort within the Army system engineering process responsive to acquisition program schedules and milestones. The LSA is a composite of systematic actions taken to identify, analyze, quantify and process logistic support requirements. The analysis evolves as the development program progresses. The number and type of iterative analysis vary according to the program schedule and complexity. As the LSA evolves, records are maintained to provide the basis for logistic constraints, identification of design deficiencies, and identification and development of essential logistic support resources.

Initially, the LSA develops qualitative and quantitative logistic support objectives. As the program progresses, these objectives are refined into design parameters for use in design/cost/operational availability/reliability centered maintenance/capability tradeoffs, risk analysis and development of logistic support capabilities. The initial effort evaluates effects of alternatives, hardware designs on support tasks and operational readiness. Known scarcities, constraints or logistic risks are identified, and methods for overcoming or minimizing these problems are developed.

During the design process phase, analysis is oriented toward assisting the designer in incorporating logisitc requirements into hardware design. The goal is to create an optimum system/equipment that meets the specification and is most cost-effective over its planned life cycle. Logistic and reliability centered maintenance deficiencies, as design evolves, becomes considerations in tradeoff studies. Periodically the design and the hardware is subjected to a formal appraisal to verify supportability features such as accessibility and compatibility of test equipment as specified in the contract.

As the program progresses and designs become fixed, the LSA process concentrates on providing timely, valid data for all areas of ILS; e.g., maintenance, provisioning, personnel and training, and technical publications. Detailed logistic support requirements are identified as the design of the end item becomes firmly established. The range and depth of analysis varies depending upon the extent of system/equipment design definition

and the goal of the analysis. Some analyses are highly iterative, while others are a one time effort. Feedback and corrective action loops are used as controls to assure that deficiencies are corrected and documented.

7-7.5 LSA PLANNING

LSA planning is implemented by the procuring activity as an integral part of the ILS program. Detailed definition of LSA planning requirements are delineated in the Request for Proposal and Statement of Work. The contractor specifies, in his response to the RFP, the methods to be employed in implementing and controlling the LSA process. Unfortunately on competitive type development programs such as the UTTAS and AAH LSA, planning is limited to that contained in the respective development plans. As an example, the maintainability program on the AAH is structured to require the contractors to perform certain tasks that are designed to provide design influence, visability and program control. These tasks are internal to the competitive contractors, but there are provisions for the project manager to monitor progress and assess program effectiveness.

7-7.6 LSA INPUT/OUTPUT REQUIREMENTS

The LSA has input/output relationships with operational requirements, reliability and maintainability programs, and other design related disciplines. A system of data processing controls is used by the contractor to manage LSA inputs and outputs - Inputs are data required for performance of the LSA process. Outputs are data resulting from the LSA process, filed in the LSA Record, and used internally by contractor functional elements or delivered to the Government Contracting Officer in accordance with the Contract Data Requirements List (CDRL). Data generated within the LSA process adheres to the data element definitions and codes provided by MIL-STD-1388-2. Input/output data requirements are kept to the minimum essential to the LSA process.

7-7.6.1 Inputs

Input data for the LSA generally falls into two basic categories, Government provided policies, concepts and applicable historical data and data provided by cognizant Government and contractor functional elements; e.g., reliability, maintainability, systems engineering and logistic support. Inputs required to manually or mechanically summarize logistic requirements are illustrated in the sample input data sheets in Figures 7-6 through 7-10.

LSA INPUT DATA SHEET	END ITEM OPNS AND MAINT. REQ. A	ITEM R & M CHAR. B	TASK ANALYSIS SUMMARY C	MAINT. AND OPERATOR TASK ANALYSES D	SUPPORT AND TEST EQUIP. OR TRAINING MATERIAL DESCRIP. AND JUST. E	SPECIAL FACILITY DESCRIP. AND JUST. F	SKILL EVAL. AND JUST. G	SUPPLY SUPPORT REQ. H
SYSTEM	X	X	X	X	•	•	•	X
SUBSYSTEM	•	X	X	X	•		•	X
LOWEST REPARABLE ASSY.		X	X	X				X
PART								X

X = Data Sheet normally required.

• = Data Sheet dependent upon program requirements.

Figure 7-6. LSA Input Data Sheet Utilization

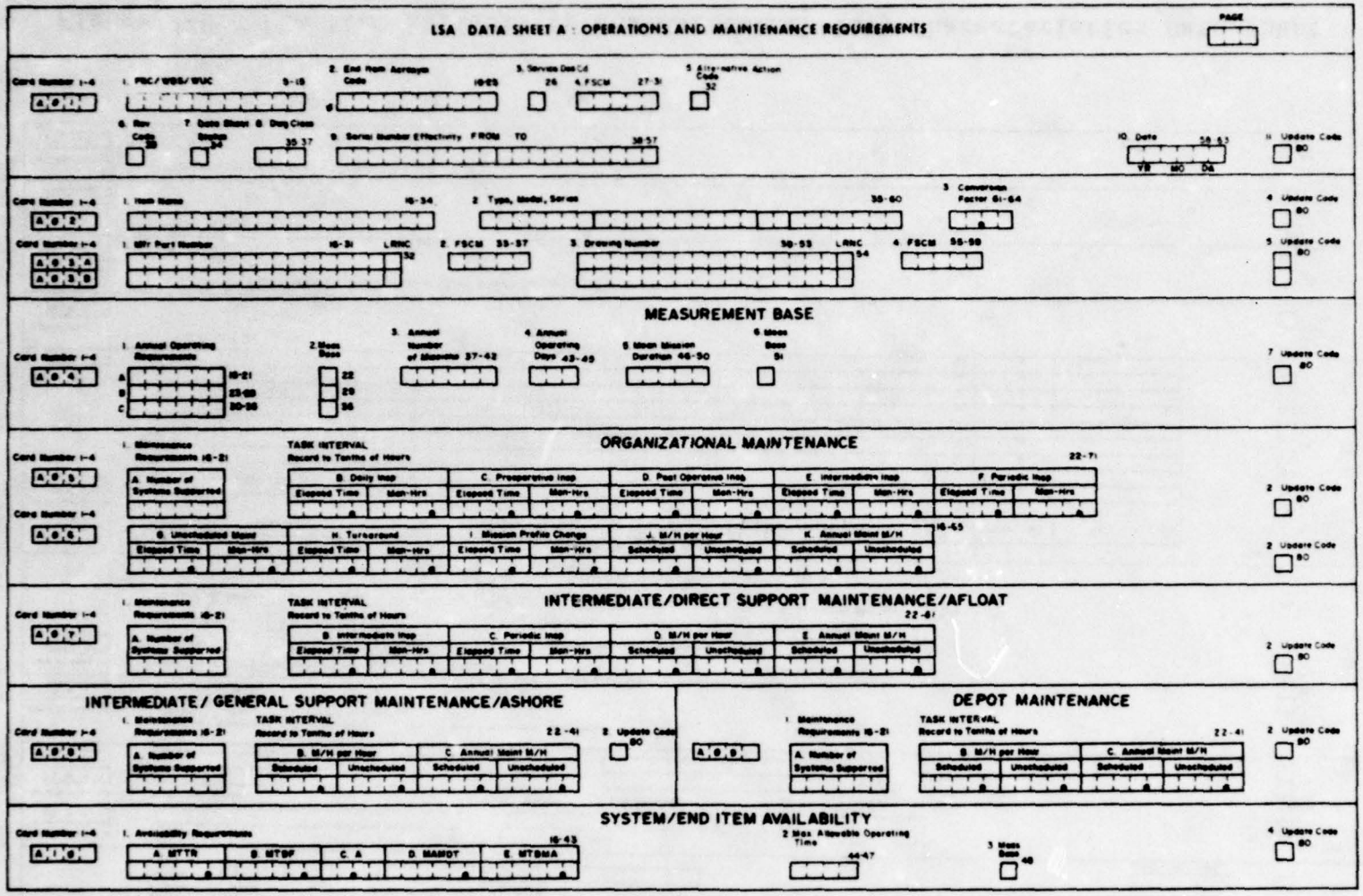


Figure 7-7. LSA Operations and Maintenance Requirements Data Sheet

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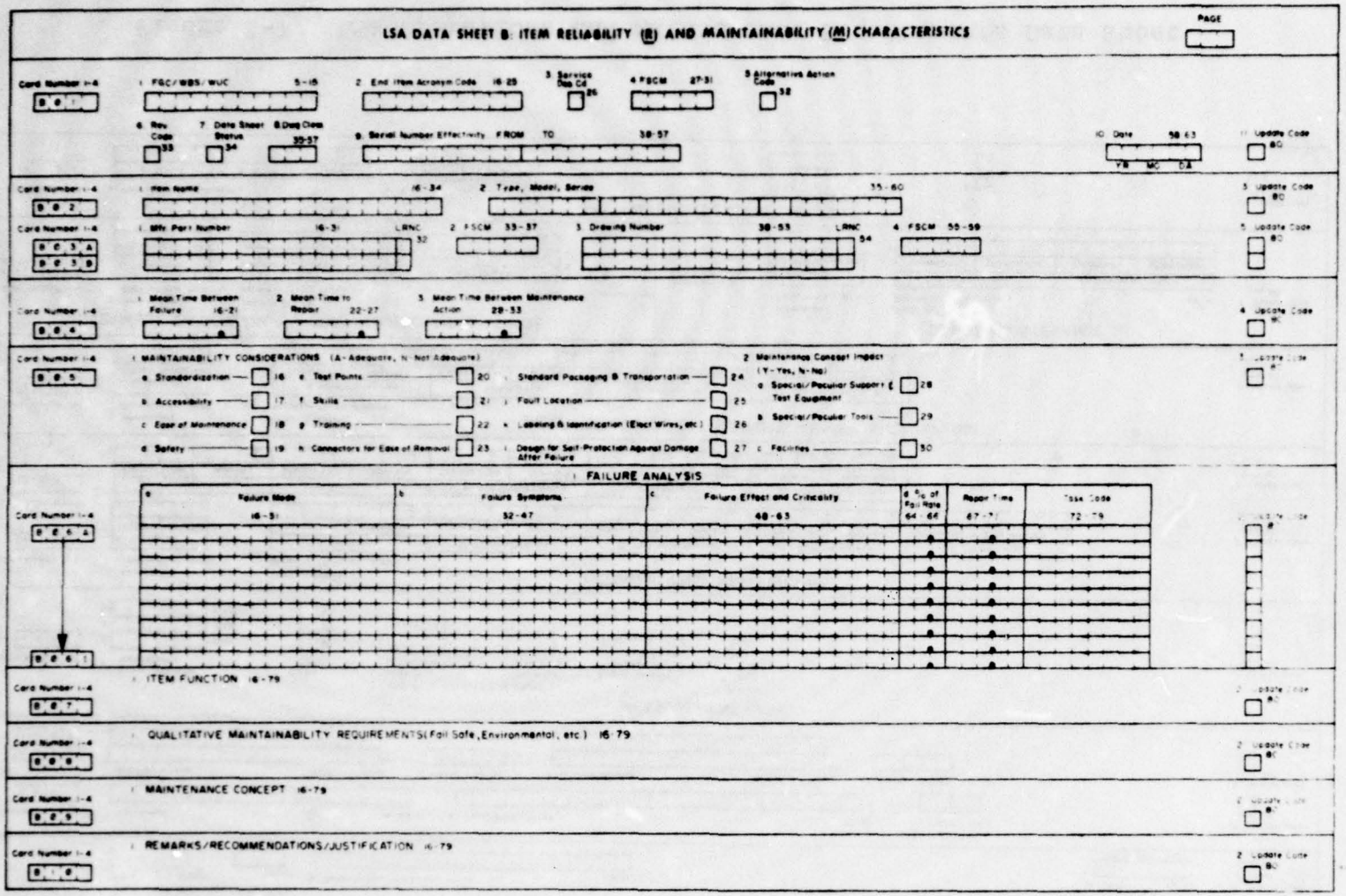

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Figure 7-8. LSA Item Reliability and Maintainability Characteristics Data Sheet

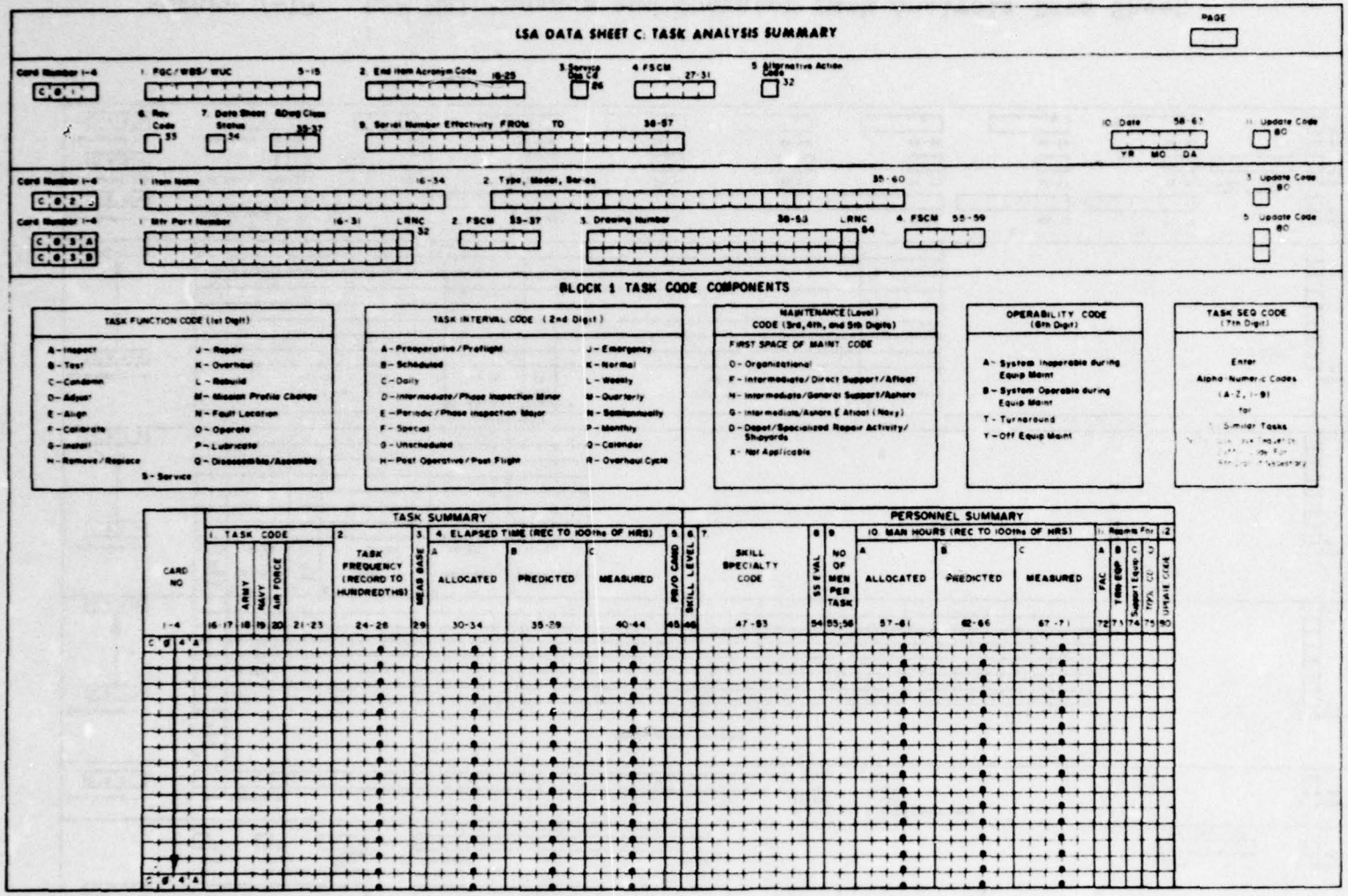

Figure 7-9. LSA Task Analysis Summary Data Sheet

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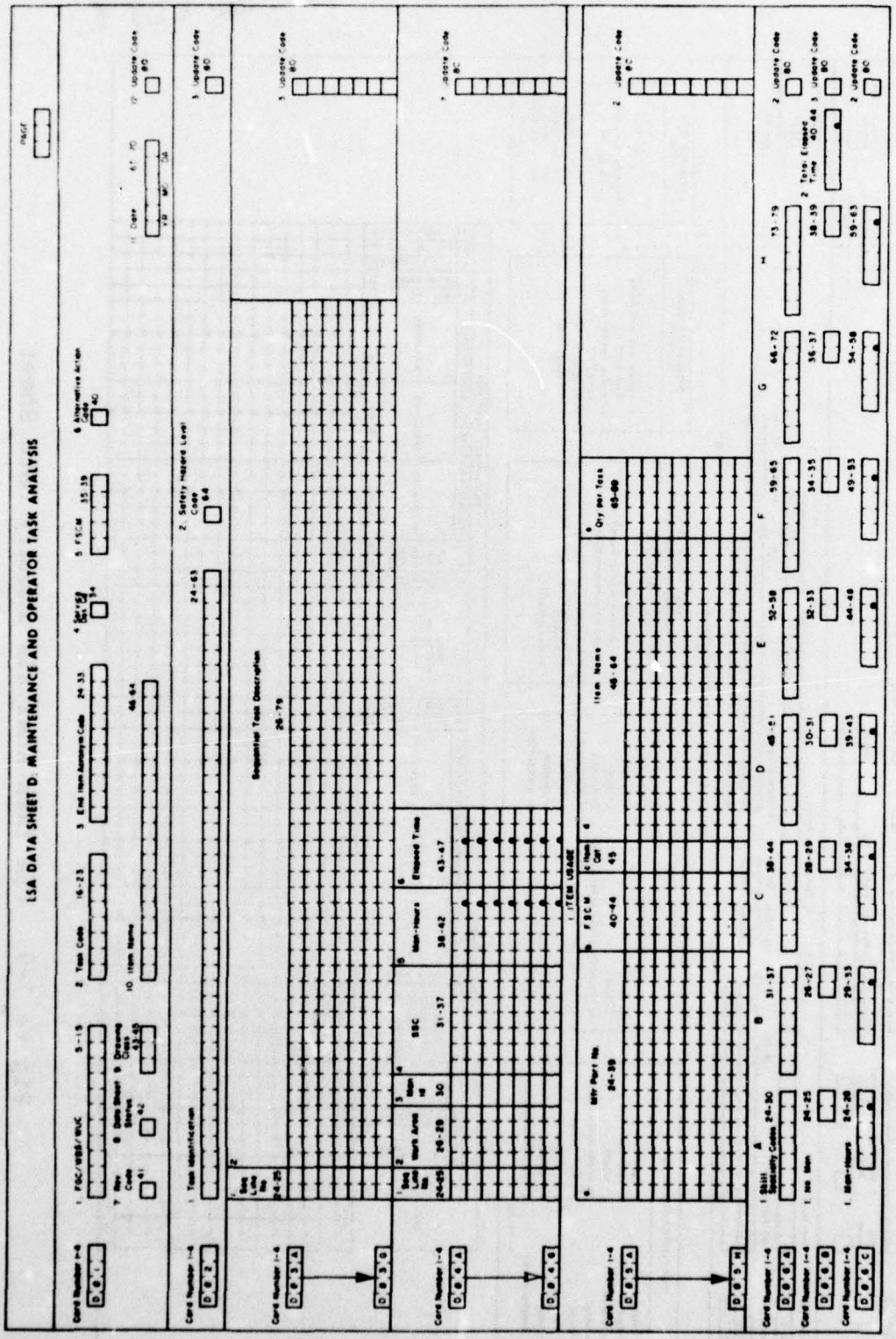

Figure 7-10. LSA Maintenance and Operator Task Analysis Data Sheet

Data provided by the procuring activity normally include operational requirements; special constraints; long range maintenance; supply and personnel policies; economic factors; existing equipment lists; facilities criteria; environmental considerations; existing service training capabilities; existing skills; Government Furnished Materiel; and maintenance support concepts.

Data from Government and contractor functional elements include but are not limited to, reliability and maintainability predictions; drawings; specifications; milestones; usage and inventory data; transportability data; test results; operator and maintenance task analyses data; technical publications details; facilities utilization factors; site data; and packaging procedures and materials.

7-7.6.2 Outputs

Information developed by the LSA shall determine logistic support requirements. The LSA process is also a source of logistic data applied to the system design effort in the form of design constraints recommended for improving maintainability and supportability. LSA provides data to risk analysis, effectiveness studies, system tradeoff studies, data for establishing maintenance factors, data for determining scheduled and condition maintenance for system and components.

The LSA provides qualitative and quantitative data used for provisioning, maintenance planning, facilities design, technical publications, support system engineering, personnel and training plans, and the Packaging, Handling, Storage and Transportability Program.

More specifically, LSA documentation will identify and describe support and test equipment; facilities requirements; personnel required by skill, type and number; spares and repair parts; and quantification of maintenance and operational support needs.

7-7.7 LSA RECORD (LSAR)

The LSAR is developed as the single source of validated integrated design-related logistic data pertaining to the acquisition program.

7-7.7.1 LSAR Format

The LSAR contains standardized data elements defined in MIL-STD-1388-2 whenever qualitative and quantitative LSA data match the given data element definitions. Additional data elements, peculiar to a specific acquisition, may be authorized by the procuring activity. The input/output formats and filing system for these records are established in a manner that best compliments the technical data systems of the program and assures integration of the logistic elements with design. These records may be manual, automated or hybrid.

7-7.7.2 LSAR Contents

Formal data is maintained only for those items determined to be subject to maintenance operational actions, unless otherwise specified by the procuring activity. Accumulated logistic support requirements data provide a basis for logistic actions such as provisioning, preparation of technical publications, maintenance planning, resources allocation, preparation of allowance lists and manning documents, identification of facilities and storage/stowage requirements, and funding decisions. The LSAR is updated to reflect changes to logistic support data resulting from tests, configuration changes, or operational usage.

7-7.8 LOGISTIC REQUIREMENTS IDENTIFICATION

Logistic resources requirements associated with the proposed design configuration as identified and refined as the proposed system/equipment progresses from program initiation through full-scale development. The extent of identification depends upon the magnitude and complexity of the system/equipment and the phase of the acquisition cycle. As development progresses and the basic design configuration is established, the identification becomes a process of analyzing specific design data to more completely identify detailed support system requirements. This portion of the LSA defines the requirements of the principal elements of ILS, as shown in Figures 7-11 and 7-12.

7-7.8.1 Maintenance Planning

The maintenance plan for the system forms the basis for tracking the other elements of ILS. Initially, the LSA strives to establish concepts and goals that the program must achieve in regard to the maintenance characteristics of the system. Throughout the

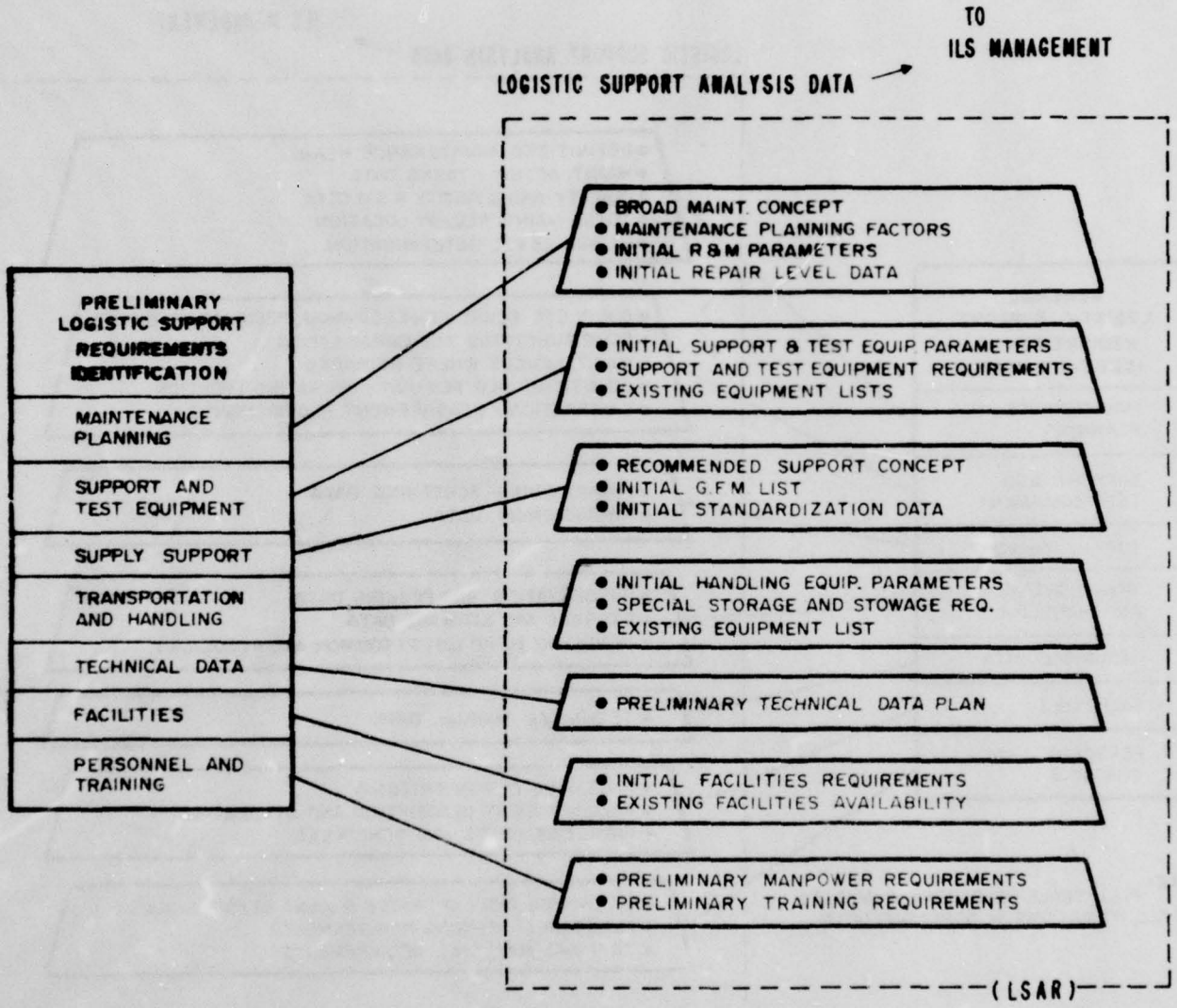

Figure 7-11. Program Initiation Phase

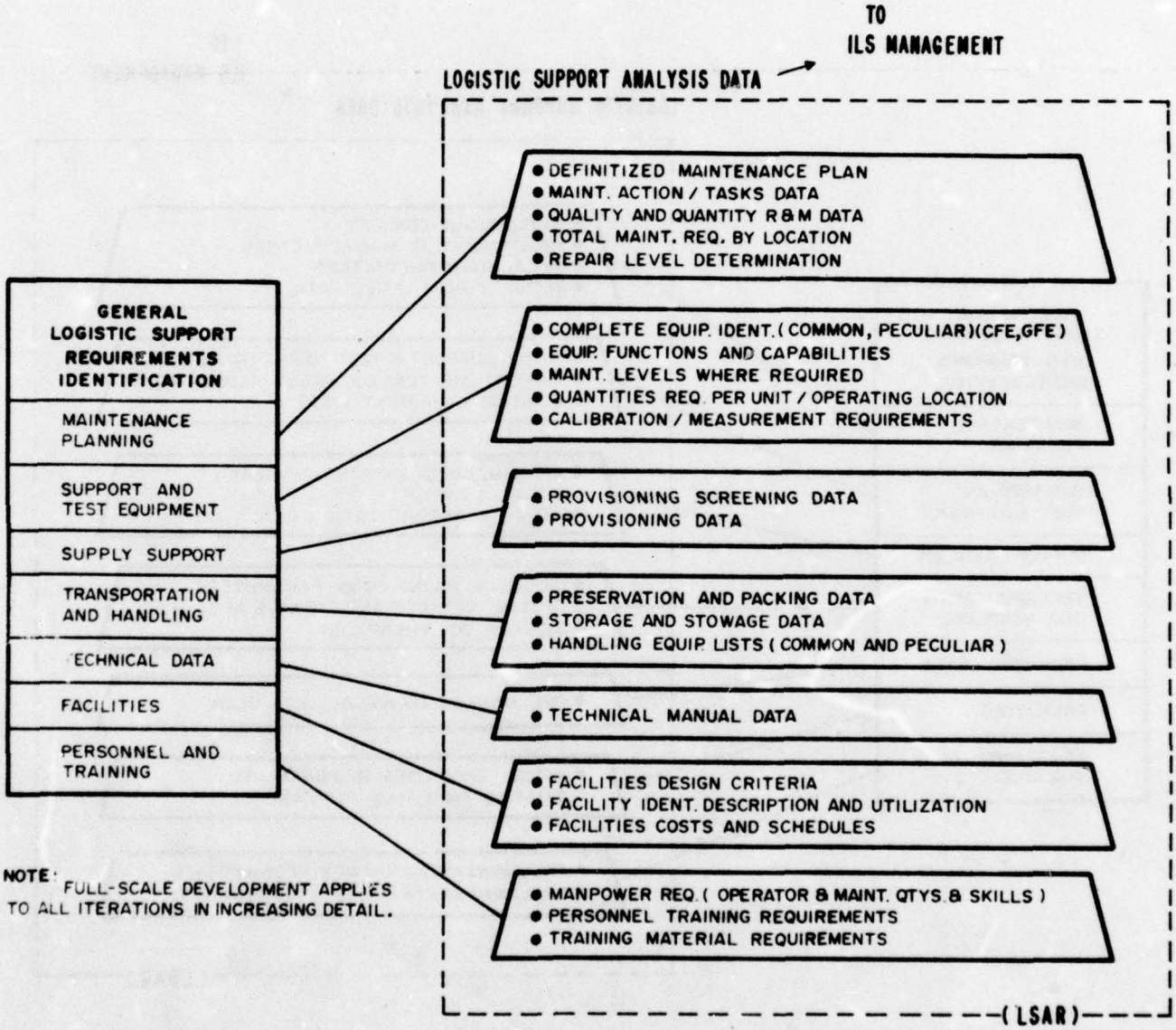

Figure 7-12. Full Scale Development Phase

Program Initiation and Full-Scale Development Phases, LSA documentation keeps pace with and reflects the current state of proposed maintenance for the system. This is done by describing to increasingly lower indenture levels the maintenance and supply support required by the system. Data required from the LSA for detailed definition of the maintenance and requirements; maintenance tasks (time and skills); descriptions of maintenance organizations; broad support and test equipment requirements; maintenance standards; broad supply support requirements; and facilities requirements.

Initial studies are conducted to establish the maintenance level at which each hardware item will be replaced, repaired or discarded. The repair level determination provides the initial basis for maintenance planning. The necessity for an economic evaluation is determined as early as possible. A non-economic engineering evaluation, which examines such factors as item size, safety requirements, technical feasibility of repair, and required support and test equipment is always performed. The economic evaluation includes cost factors pertaining to operations, preventive maintenance, repair, inventories, documentation, and disposal. Mathematical models for economic repair level determination are used if the size of the system under development indicates such an approach is cost-effective. Detailed non-economic and economic (when required) repair level determinations are accomplished prior to completion of full-scale development.

7-7.8.2 Support and Test Equipment

The LSA provides a comprehensive identification of support and test equipment requirements at all levels of repair. During program initiation, usable existing equipment is identified so that development of peculiar equipment is held to a minimum. A major constraint on support and test equipment requirements is that Standardization Program required by MIL-STD-680. A primary data source in the determination of equipment needs is the Task Analysis, which also defines the still levels necessary to operate and maintain the equipment. Support and test equipment data resulting from the LSA include complete equipment identification; maintenance level at which required; quantity of equipment required per organization, per operating location; equipment function and capability; calibration requirements; and spares and repair parts lists.

7-7.8.3 Supply Support

The LSA identifies system requirements by maintenance level and frequency of use, for spares, repair parts, and consumables, to include War Readiness Material when appropriate. Requirements for operations consumable supplies and material such as fuel, lubricants, oxygen, etc., are also determined. Impacts upon storage spaces, supply facilities, equipment, personnel, and procedures are evaluated for each support system approach under consideration. Supply data resulting from the LSA include spares and repair parts provisioning; consumption and usage rates; recommended allowances; supply storage requirements (PHST data); and Source, Maintenance and Recoverability (SMR) coding.

7-7.8.4 Transportation and Handling

The LSA provides data pertaining to packaging, handling, storage and repair turnaround times to the Packaging, Handling, Storage and Trasnportability (PHST) Program. Conversely, PHST data affecting operations, maintenance and provisioning are inputs into the LSA. As the design evolves during full-scale development, LSA data is continuously being refined and updated. The LSA supports the PHST program in providing design feedback to insure that the system/equipment, support and test equipment, spares and repair parts are designed wherever possible, to be compatible with available modes of transportation and existing handling equipment. PHST data resulting from the LSA include equipment physical dimensions; container requirements and codes; storage and stowage space; preservation and packaging requirements; and handling constraints.

7-7.8.5 Technical Data

The LSA provides information from system/equipment design, operations, maintenance, and supply support which is essential for development of technical publications and provisioning lists. Levels of details in the LSAR are progressively expanded and refined throughout program initiation and full-scale development. Use of the LSAR reduces duplication of data and related effort, which will contribute to preparation and delivery of accurate, adequate technical publications in a timely, economical manner.

7-7.8.6 Facilities

The LSA identifies the facilities required to support a system/equipment throughout system testing, training, operations and

maintenance. Preliminary information developed during program initiation will be further refined so that timely facilities planning may be accomplished. Facility considerations include requirements for mobile, portable, and air transportable vans; mobile maintenance facilities; shops; training facilities; supply storage; and bulk storage containers, as operational, maintenance and support concepts dictate. Changes and improvements in the system/equipment design are reflected in facilities requirements when appropriate. Realistic scheduling makes optimum use of facilities and at the same time permits timely performance of maintenance functions. Facilities data resulting from LSA include facilities identification and description; facility design criteria; facilities costs; and leadtimes.

7-7.8.7 Personnel and Training

The LSA identifies the personnel, training and training material required for the support of the system/equipment. Coordination is maintained with cognizant design activities so that applicable design changes are reflected in the Personnel and Training Plan. Analysis provides identification of the requirements for trained operators, support and instructor personnel at all organizational levels. Personnel and training data resulting from the LSA include personnel quantities needed; skill levels; skill specialties; training requirements; training facilities; and training materials.

7-7.9 LSA DATA VERIFICATION

LSA data verification is conducted continually to correct and amplify the LSAR. Initially verification if performed to update preliminary LSA data. Later, as system/equipment design progresses, ILS verification tasks become formal evaluations to assess whether the logistic support system will effectively and economically maintain the end item. Data feedback from maintainability demonstrations, support and test equipment compatibility tests, and technical publications validation and verification actions is assured to provide corrections to affected LSA data. The degree of Government/contractor participation in LSA verification is as specified by the procuring activity.

7-7.10 ENGINEERING INTERFACE

Engineering interfacing signifies control actions established to assure that the outputs from engineering speciality areas are compatible coordinated data.

7-7.10.1 Design Factors

Design factors are those LSA inputs from system and design engineering which are essential to the integration of ILS into the system engineering process. Data normally include the following: drawings; specifications; Contract Work Breakdown Structure; Work Unit Code assignments; support engineering data resulting from integration of the support system with the equipment system; and data based on the interplay between specialized engineering factors; e.g., Reliability, Maintainability, PHST and Standardization.

7-7.10.2 Reliability Factors

The System/Equipment Reliability Program, performed in accordance with MIL-STD-785, provides the following types of input data to the LSA: reliability apportionment/predictions; the effects of storage, shelf life, packaging, transportation, handling and maintenance on reliability; Failure Mode and Effects Analysis (FMEA) data; and a preferred parts list. These data interface with and are impacted by the Standardization, PHST and System Safety Programs. A major task is the FMEA, which is used for timely identification of predicted system/equipment failures and the effects of these failures on the total system. FMEA is a continuing effort affecting system/equipment design and the logistic support system. Examples of FMEA data inputs to the LSA are item failure modes; failure rates; failure symptoms; failure criticality; failure effects; and detection methods.

7-7.10.3 Maintainability Factors

The System/Equipment Maintainability Program, conducted in accordance with MIL-STD-470, provides detailed qualitative and quantitative maintainability requirements and maintenance plan details as inputs to the LSA. Maintainability task analysis data, predicted parameters, design guidelines and demonstration results are included. Two major tasks are discussed below.

7-7.10.4 Maintainability Predictions

Maintainability predictions provide system/equipment maintainability parameters used in estimating system maintainability values associated with hardware indenture levels. Initially, quantification may be limited by uncertainty of design and scarcity of data. Best estimates will be used in conjunction with LSA data pertaining to repair levels, logistic support resources

and optimized support characteristics. During full-scale development, prediction techniques will provide quantitative estimates of maintainability parameters for use in identifying design features requiring corrective action and in determining logistic support requirements. Examples of maintainability predictions which are inputs to LSA include mean-time-to-repair, mean-down-time, and maintenance manhours per operational increment.

7-7.10.5 Maintenance Task Analysis

A repetitive maintainability analysis provides data used in defining the resources required for maintaining the system/equipment. Specific analysis outputs include:

(1) The delineation, by maintenance level, of specific maintenance tasks necessary to sustain the equipment in, or return it to, operating condition.
(2) Task times and frequencies.
(3) Personnel requirements (skill levels and quantities).
(4) Training and training equipment requirements.
(5) Support and test equipment, spares, repair parts, and consumables.
(6) Facility requirements.

As in many areas of LSA, the task analysis is evolutionary, performed in greater detail as the design is defined. Maintenance times and personnel requirements are estimated in the Program Initiation Phase and defined in detail as the design progresses through the Full-Scale Development Phase. The FMEA is the primary source of data for identification of corrective and preventive maintenance tasks. When detailed design data are available, tasks are organized into step-by-step procedures which are used as the basis for technical data preparation. Examples of task analysis detailed inputs to LSA are task descriptions; sequential actions comprising a task; task frequencies; manhours per task; personnel requirements per task; replacement parts per task; and support and test equipment per task.

7-8 MODELING AIDS FOR LOGISTIC SUPPORT ANALYSIS

7-8.1 LOGISTICS MODELS AS TOOLS IN EARLY PLANNING FOR SUPPORT

ILS is a composite of all the support considerations necessary to assure the effective and economical support of a system for its life cycle. (Reference 4) It is an integral part of all other aspects of system acquisition and operation. ILS begins

with program initiation (conceptual and validation phases) and continues through full-scale development, production and deployment.

The choice of test equipment is inherent in the ILS process and the alternatives available to the acquisition manager are not the same for each phase in the life cycle. During conceptual effort, the focus is on system feasibility studies and the major output is the basis for a decision as to whether a system acquisition program should be pursued. Support activity during the conceptual phase is concerned with defining the maintenance environment, the interface with the logistic systems, and such goals as mean-time-between-failures (MTBF) and mean-down-time (MDT). That is, the support activity is dealing with requirements which will be the basis for later selection of test equipment to meet the requirements.

In the advance development phase, the requirements for built-in-test/built-in-test equipment (BIT/BITE) are developed and baseline maintenance concepts are specified. The role of separate test equipment emerges at intermediate and depot levels in relation to BIT/BITE.

During conceptual effort and advanced development, various simulation processes are used to anticipate the effect of different approaches. Firm descriptive data, (such as exact frequencies of operation, equipment failure rates, etc.) is not available. The relationship of many variables (such as failure rate as a function of equipment utilization) is better known than the numbers themselves. In such a situation, simulation processes are useful in giving an answer to "what if" questions. For example, what if the required operational availability is so high that MDT cannot exceed ten minutes? Or what if there were no intermediate level of support, and faulty items were returned from the fleet user directly to depot? The tools which simulate the relationship of the variables in a process are called models. Models are a part of the ILS tools of the trade. They are used to indicate what is significant and what is not in planning the long term support of an equipment.

They can anticipate the effect of suddenly increasing the usage rate of an equipment by a factor of 2:1 or the savings in support costs of achieving an additional ten percent MTBF during design.

The logistician uses models to help define the elements of logistic support in time to impact design, plan for equipment deployment, and control maintenance costs. Models can also be useful to those concerned with implementing the support concepts developed by the logistician, i.e., those concerned with selection of test equipment.

7-8.2 DECISION POINTS WHICH CAN BE SUPPORTED BY MODELING

Figure 7-13 indicates the phases in an equipment's life cycle and the test equipment related activities are indicated in the flow of tasks. There are many other activities which are not shown; the activity flow was drawn especially to emphasize test equipment related elements.

In the conceptual and advanced development or validation phase, test equipment decisions are of the type "what generic kind of test equipment should be anticipated in support of these operational and maintenance requirements"? It is too early in the life cycle, for most prime systems, to select test equipment A or to evaluate test equipments A, B, and C. Rather, the range of decisions would include a choice of:

(1) Whether an operational availability can be better achieved with built-in test, separate test equipment, or a combination of both

(2) Whether board and subassembly fault isolation/repair can more effectively be accomplished using manual general purpose test equipment, general purpose ATE, or special purpose ATE unique to the prime mission equipment

(3) Whether overall savings accrue from using the same test equipment at intermediate and depot levels although the testing requirements are different.

Before moving to full-scale development, the support concept should be defined (level of repair, built-in test decisions, etc.). Models will be very much in evidence as the support concept is firmed and early test equipment decisions are made. At this stage input data consists of such operational parameters as:

(1) Availability
(2) Utilization rate
(3) Deployment
(4) Reliability

and such program requirements as

(1) Unit cost targets
(2) Service life

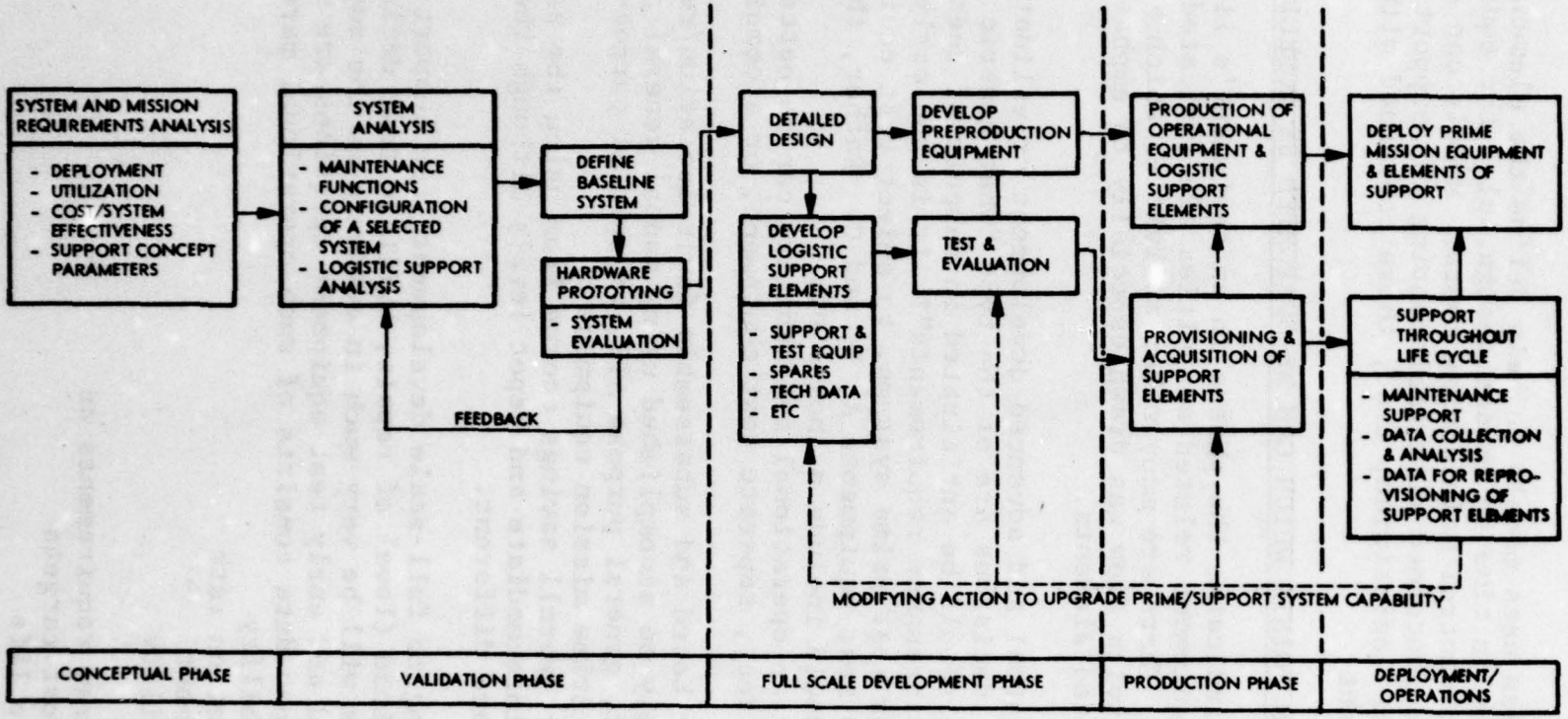

Figure 7-13. Equipment Life Cycle

A second area where models are likely to be useful in supporting test equipment decisions is during development and production. During some time in the development phase, a specific test equipment must be selected. This test equipment may be a developmental requirement described by an equipment specification; it may be itself in development.

The input data available to the model would consist of:
(1) Specific prime equipment test requirements
(2) ATE interface requirements in terms of number and types of connectors, test access points, power requirements
(3) Workload requirements in terms of the numbers and types of units to be tested per unit time which arrive at the test station
(4) Personnel subsystem characteristics, operator training assessments.

In general the input data could be expected to be quantitative, with an accuracy confidence derived from design data and limited test/evaluation. Sensitivity analysis would be used to identify parameters critical to the ATE selection.

A third application for support system modeling is when the overall support resources must be estimated. Support resources are all the elements of test equipment, spares, operator/maintenance personnel, tech data, periodic calibration, etc. which are needed to maintain the prime mission equipment. After an equipment is deployed in the field, along with supporting test equipment, there are frequently changes in the number of equipments, in where and how they are used, and as significant modifications to the basic equipment. When such changes are contemplated, modeling techniques are useful in anticipating the impact of change. For example, increasing the number of equipments may change the test workload such that additional test equipment is needed. Models are used to anticipate the total resource requirements resulting from:
(1) A modified support concept, such as off-loading board repair to intermediate or depot level
(2) The opportunity to replace obsolescent test equipment with more efficient newer design
(3) Major modifications which results in new test requirements
(4) Data indicating significant increase in prime equipment failure rates and therefore reduced maintenance workload.

The models discussed in this section are mathematical models. That is, the relationships of independent and dependent variables in the maintenance process are expressed in mathematical terms and converted to a program which runs on a general purpose digital computer.

There are two basic approaches to expressing the relationships within the model and each approach has distinct advantages and disadvantages for one or another application. The two approaches are identified as analytical and simulation models. The analytical model provides a single answer or set of answers for a given set of inputs. The analytical model gives an answer for all input values held fixed. The simulation models trace the behavior of the process over a time period during which key variables are allowed randomly to assume some value within its range of possible values.

7-8.3 GENERIC MODEL TYPES AND THEIR CHARACTERISTICS

It is generally a characteristic of analytical models that they provide solutions with relatively small computation effort. The relationships between various factors may be complex but most likely or best estimate values are used to obtain a single point solution.

The formulations within the model are of a type in this simple example:

$$AFD = IUD/(UD + IUD)$$

where

AFD = an apportioning factor for support equipment at depot
IUD = item utilization of support equipment at depot
UD = utilization of depot level repair support equipment per month on other items

AFD is expressed as a fraction of time, such as .3 or .4 while IUD and UD are in hours and hours per month respectively.

Most reliability models are analytical models, based on a formulation relating the probability of occurrence of various events. The function of failure rate prediction is closely related to maintenance workload estimation.

Other analytical models are useful in examining processes which involve the flow of material between geographic locations, such as repairable items and spares stocks between maintenance levels.

It is a characteristic of analytical models that computer running time is short - on the order of seconds or a few minutes. This means that the user can expect to get responses quickly and cheaply, and he will be able to iterate various solutions as the most significant characteristics emerge in the trial solutions.

Typically, the technique of sensitivity analysis is used within analytic models as a way of handling input data uncertainty. The classical parametric study is an example of sensitivity analysis, where a range of solutions are presented for variations of akey input factor. The factor is allowed to assume values from a lowest likely to a highest likely value. Examples of sensitivity analysis will be shown in the section on input data requirements.

Every model falls short of being an exact replica which correctly relates all factors in the modelled process under all possible conditions. As such the model is a compromise, attempting to provide an adequate representation without becoming so complex or so demanding of input data that it is unwieldy to use. A support system model which neglects ATE spare parts costs would probably not adequately represent significant cost elements; a model that required an individually priced spare parts list would require more effort than it is worth in generating input data.

Typical input data would include that shown in Table 7-3. The input data requirements are more a function of the process being modelled than of the type of model.

Analytical methods are particularly applicable to reliability and maintainability models, to resource allocation models, to life cycle cost and logistic models, and to optimization problems where the best of alternatives is to be chosen.

Systems characterized by large data banks or sizable solution sets can be handled with simulation models. Simulation traces the system's behavior, frequently over time, under a specific group of constraints, such as initial conditions, exogenous and design variables, target conditions, and internal structural properties. Functional relationships exist between the solution parameters and the control or state variables in the model, and in some cases the solutions are not obtained as point estimates but rather as intervals that contain the correct answer.

TABLE 7-3. EXAMPLE PROBLEM DATA BASE

- Deployment Factors - Number of systems supported, geographical location, utilization rate, support hierarchy to include relation to organizational structure, and work week
- Equipment Factors - Equipment breakdown, units, components, modules, parts; failure rates; physical characteristics; operating times; and costs per unit, module and part
- Supply Factors - Stockage policies, supply times, production lead times, stockage costs, and transportation factors
- Unit Modifications - Modifications of unit/component and the provision quantity during the operational phase of the program
- Test Equipment Factors - Test equipment characteristics, costs, and support maintenance requirements

Although simulation is frequently implemented for complex situations, it is not necessarily true that the solution implied from a given set of input data is optimal. Instead, it represents an approximation to the best answer, and the modeler must introduce various input combinations to compare their implications for the desired goals in the system analysis. Yet, even with the selection of many different input data, the attainment or realization of an optimal solution cannot be assured as it is for the analytical approach.

Although simulation is generally more adaptable to large-scale computational problems than analysis, it also gives approximate solutions whose optimality may, or may not, be justified on theoretical grounds. Further, simulation models are generally larger, more difficult to debug and validate, and more expensive to run than analytical models. They can be used, however, to analyze situations that are just too complex for analytical models to handle. They are thus exceedingly useful for analyzing complicated systems in uncertain environments (Reference 5).

Simulation models are particularly useful when it is desirable to examine a complex process operating over a long time frame. For example, it may be desirable to consider the maintenance workload at a vehicle maintenance facility over a year's time,

during which the number of vehicles supported, their equipment complement and time in service would vary on a day-to-day basis. Simulation type models would provide a picture of the workload ebb and flow, showing times of overload and times of very little workload. The results would be synthetic, i.e., they portray a situation which could occur but would most likely not be precisely duplicated in real life. There are situations, such as the work shop example, where the modeler wishes to simulate a dynamic situation in which independent variables are allowed to assume any value within a likely range.

The disadvantage is that simulation models can be costly to run because of their complexity and the user still lacks insight from the solution as to which of his parameters have the greatest impact on the system.

REFERENCES

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3. Defense Management Journal, Design to Cost Special Issue, September 1974, "A Design to Cost Overview", Pages 2-7.

4. DoD 4100.35-5, Integrated Logistic Support Implementation Guide for DoD Systems Equipment.

5. Rand Report R-550-PR, Using Logistic Models in System Design and Early Support Planning, February 1971.

CHAPTER 8
PERSONNEL SKILLS AND HUMAN FACTORS

SECTION I

MAINTENANCE PERSONNEL SKILL AND AVAILABILITY

8-1 GENERAL

It is vitally important for the design engineer to consider the skills required and the personnel available to operate and maintain the equipment he designs. Equipment that required skill levels higher than those that can be made available cannot be successfully maintained. If the maintenance skill level required is much in excess of that available, the equipment can be a liability instead of an asset because it wastes maintenance manpower and supply-channel effort.

It is difficult to obtain and retain skilled military maintenance personnel. Therefore, everything possible must be done by the designer of equipment to build in maintenance features that would make unnecessary highly skilled technicians for effective maintenance.

As the complexity of equipment increases, the time required to train the operator or maintenance specialist also increases. The current normal military enlistment tour is three years (Ref. 1). While a considerable number of persons re-enlist one or more times, there is no obligation for an individual to do so. Thus, there is a definite factor of diminishing returns in a long training program. In a study of Army electronics personnel, for example, it was found that "for every ten men trained as radio, microwave, or radar repairmen, generally one re-enlists while the other nine enter civilian employment". Equipment should therefore incorporate maximum simplicity to permit the shortest possible training time so that the technician's effective service after training can be proportionately increased.

Complex or inaccessible equipment will generally require greater skill to operate and be more difficult to service. Because

of this, it is more vulnerable to human failure when the user is under tension or emotional stress. This can be a critical problem in combat or emergency situations.

8-2 THE TYPICAL MAINTENANCE TECHNICIAN

In the design of Army equipment, the user skill level should be considered from the initial design stage through the life cycle of the product. The optimum design goal should be equipment that can be operated and repaired effectively by the least experienced personnel with little or no outside assistance. For development purposes, the "typical" Army technician shall be assumed to possess the following characteristics:

(1) Age. The median of the age distribution is 21.2 years, with 55% of all technicians between 20 and 22 years of age.

(2) Average civilian education. The average number of years of civilian education is 12. Only 15% will have attended college and less than 1% will have graduated from college. Only 1 out of each 1000 will possess an engineering degree.

(3) Average service education. Formal service schooling will consist of 19 weeks, to include basic training, specialty training, and weapon system training.

(4) Applicable civilian experience. None.

(5) Applicable army experience. Overall average is approximately 3.5 years, but the technicians who will perform most of the work (nonsupervisory) can be expected to have 2.3 years of experience.

(6) General limitations. The "typical" Army operator or maintenance technician should not be required to:

- (a) read at higher than the 9th-grade reading level.
- (b) perform arithmetic calculations, even simple addition and subtraction.
- (c) consolidate or integrate information from multiple sources.
- (d) collect, process, or report any unnecessary or complicated data.
- (e) post data from one form to another or keep any permanent records.

NOTE:

The error rates for the above operations, when performed at the weapon site as part of other maintenance duties, tend to be prohibitive.

The manpower profile of potential Army electronics personnel shown in Table 8-1 illustrates some of these points.

TABLE 8-1. PROFILE OF POTENTIAL ARMY ELECTRONICS PERSONNEL

Sample	1000 enlisted men in Basic Combat Training during September and October 1961
Enlistment information	14 of the 1000 had enlisted for training in electronics
Term of service	2 years, 59%; 3 years, 41%; more than 3 years rounds to zero
Background information	4 out of the 1000 were considered qualified for an electronics assignment without further training

Education	% of Sample	% of Group Scoring Above 100 on EL*
Information missing	8	14
Less than 12 yr	29	22
12 yr	46	42
Some college	17	63
4 yr college or more	5	70

*EL is the test score composite used to select for training in electronic maintenance. It consists of electrical information and mechanical aptitude items.

School Subjects (high school or higher)	% of Sample	Major College Subject	% of Sample
Trigonometry and chemistry	8	None	84
Trigonometry	2	Engineering	3
Geometry	13	Physical science	2
Algebra and chemistry	3	Other	11
Chemistry	1		
Physical science	30		
Physics	8		
None	24		

The line maintenance man is bored, critical, and anxious for discharge. As a result, he is not particularly receptive to training. This means that designing maintainability into equipment is about the only way to improve maintenance, other than devising detailed "cookbook" type manuals which will anticipate actions required by a technician.

8-3 CATEGORIES OF MAINTENANCE

Military maintenance is usually stratified into several levels that generally correspond both to the skill of the personnel and to the degree of difficulty of the maintenance task. Stratification by level of maintenance in the military is made essential by the demands for tactical deployment of the equipment, but it is also a solution to the problem of efficiently using maintenance men of varying skills. Periodic check-outs of electronic equipment, for instance, require a major portion of maintenance time.

This type of work, however, normally does not require a high

level of skill and can be assigned to the less skilled man, releasing the more skilled men to perform the difficult repair jobs.

The Department of the Army has grouped all maintenance into five categories: operator/crew, organizational, direct support, general support and depot.

Equipment design must adequately take into account the actual skills available at each maintenance level. Figure 8-1 shows a graphic presentation of the maintenance support concept within a field army, and Table 8-2 shows the categories and levels of maintenance in a theater of operations. A detailed description of each maintenance category is presented in the paragraphs which follow.

8-3.1 OPERATOR/CREW MAINTENANCE

Operator/crew maintenance is limited to preventive maintenance using built-in test equipment (BITE) when provided for system performance evaluation. Maintenance actions consist of visual inspection, cleaning and minor adjustments that may be performed without the use of tools.

Personnel performing operator/crew maintenance are not expected to have tools available for maintenance and are not expected to remove or replace components or assemblies nor possess any characteristics other than those described in paragraph 8-2.

8-3.2 ORGANIZATIONAL MAINTENANCE

Organizational maintenance is that maintenance normally authorized for, performed by, and the responsibility of a using organization on equipment in its possession. This maintenance consists of functions and repairs within the capabilities of authorized personnel, skills, tools, and test equipment. (This function was formerly known as 1st and 2nd echelon maintenance.)

Organizational level personnel are usually fully occupied with the operation and use of the equipment, and have a minimum of time available for detailed maintenance or diagnostic check-out. Usually, the least skilled maintenance men are associated most closely with the operation of the equipment. Maintenance at this level is normally restricted to periodic checks of equipment performance, cleaning of the equipment, front panel adjustments, and removal and replacement of some components. Personnel at this

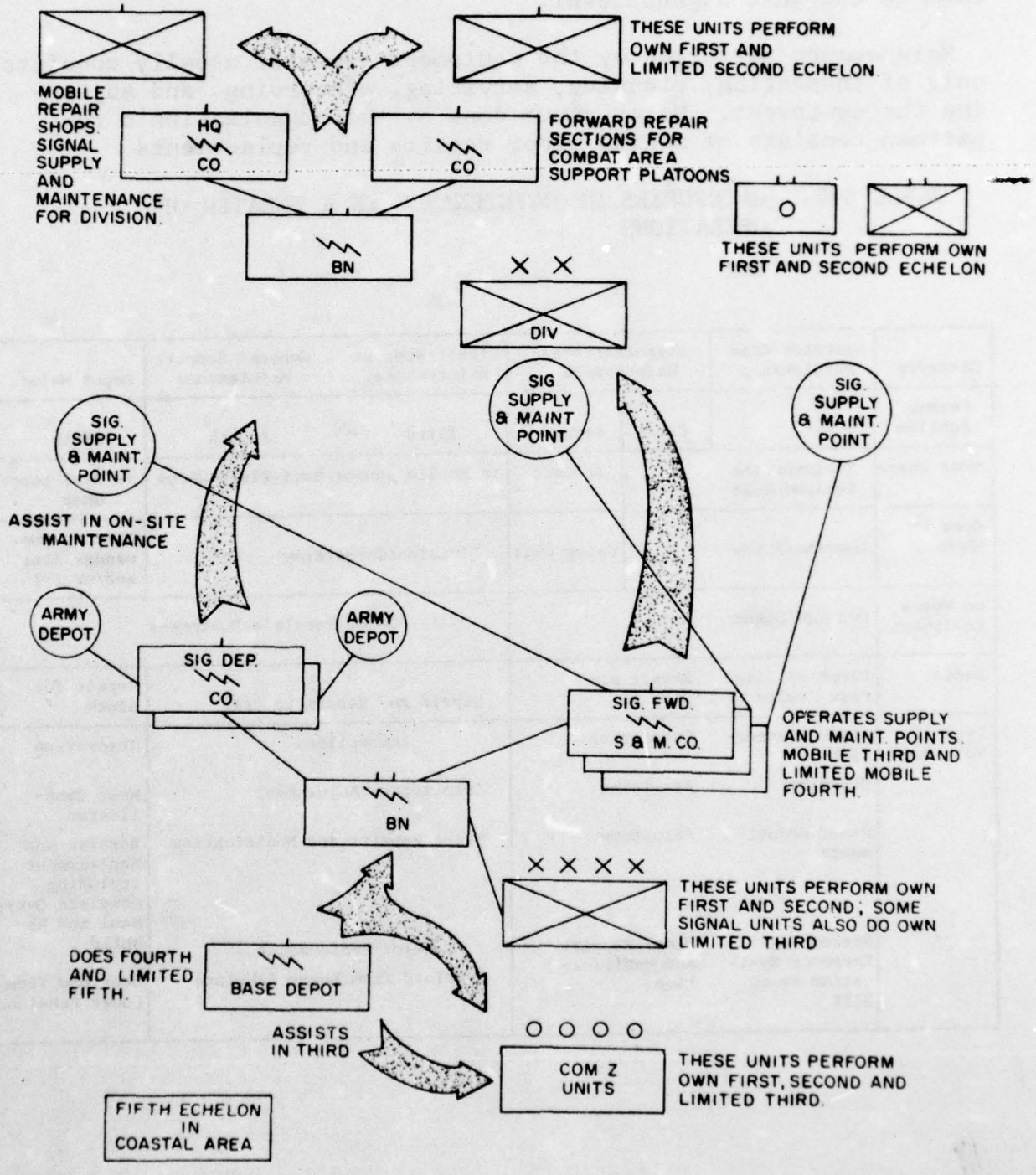


Figure 8-1. Maintenance Support Concept Within a Field Army

level usually do not repair the removed components but forward them to the next higher level.

Maintenance performed by the equipment operator usually consists only of inspecting, cleaning, servicing, preserving, and adjusting the equipment. Maintenance done by the organization's repairman consists of making minor repairs and replacements.

TABLE 8-2. CATEGORIES OF MAINTENANCE IN A THEATER OF OPERATIONS

Category	Operator/Crew Maintenance	Organizational Maintenance		Direct Support Maintenance	General Support Maintenance	Depot Maint.
Former Echelon	-	First	Second	Third	Fourth	Fifth
Done Where	Wherever the Equipment is		In Unit	In Mobile and/or Semi-Fixed Shops		In Base Depot Shop
Done by Whom	Operator/Crew		Using Unit	Division/Corps/Army		Theater Commander Zone and/or Z/I
On Whose Equipment	Own Equipment			Other People's Equipment		
Basis	Clean or Diagnose Faults	Repair and Keep it		Repair and Return to User		Repair for Stock
Type of Work Done	Visual Inspection	Inspection		Inspection		Inspection
	Cleaning	Servicing		Complicated Adjustment		Most Complicated
	Minor Adjustments	Adjustment		Major Repairs and Modification		Repairs and Replacement Including Complete Overhaul and Rebuild
	System Performance Evaluation Using BITE	Minor Repairs and Modification		Major Replacement Overload from Lower Echelons		Overload from Lower Echelons

Mobility requirements generally limit the amount of tools, test equipment, and supplies available at the organizational level. The design engineer can, therefore, expect to find personnel skills of limited specialization at this level and should plan equipment maintenance and servicing requirements accordingly.

8-3.3 DIRECT SUPPORT MAINTENANCE

Direct support maintenance is that maintenance normally authorized and performed by designated maintenance activities in direct support of using organizations. This category of maintenance is limited to the repair of end items or unserviceable assemblies in support of using organizations on a return-to-user basis. (This function was formerly known as 3rd echelon maintenance.)

Materiel that the using organization cannot repair is repaired by a direct-support unit provided it is within the latter's capability. Direct support also furnished supplies and other services directly to the user. Direct-support units are designed to provide close support to combat troops and facilitate tactical operations. This mobility requirement limits the equipment and supplies, and, therefore, the repair jobs that can be undertaken.

Military maintenance personnel at this level, however, are generally more skilled and better equipped than those at the organizational maintenance level and are charged with performing more detailed maintenance. At this level, failed components and equipment are repaired by replacement of parts and subassemblies.

Maintenance is performed by specially trained units in direct support of a "using" organization. These units are authorized larger amounts of spare parts and maintenance equipment than the using organization which the unit supports by technical assistance and mobile repair crews when necessary.

Direct-support units of fixed capabilities have been established and made an organic part of certain major combat units. Nonorganic, direct-support units help provide 100% direct support. They are of company and detachment size but can be organized into battalions and groups in any specific situation.

8-3.4 GENERAL SUPPORT MAINTENANCE

General support maintenance is that maintenance authorized and performed by designated organizations in support of the Army supply system. Normally, general support maintenance

organizations will repair or overhaul materiel to required maintenance standards in a ready-to-issue condition based upon applicable supported Army area supply requirements. (This function was formerly known as the 4th echelon maintenance.)

This level of maintenance is performed by units organized as semifixed or permanent shops. They exist to serve lower levels within a given geographical area. General-support units include companies and detachments specializing in general supply, ammunition supply, maintenance (by commodities), and other services. These units perform work that overflows from direct-support companies, but rarely deal directly with the equipment user. A general-support unit's primary maintenance function is to repair those items that cannot be repaired by direct-support units.

Units at this level must possess a certain mobility so they can remain within convenient working distance of the direct-support units. Rapid movement, however, is not as imperative here as in direct support. Some mobility is sacrificed so that they can have more time and facilities to perform their services.

A high degree of specialization can be expected at the general support level of maintenance because personnel are usually trained in schools to become experts in specific components of equipment. Mobility requirements are also less stringent and permit more complex maintenance operations.

8-3.5 DEPOT MAINTENANCE

Depot maintenance is that maintenance which, through overhaul of economically repairable materiel, augments the procurement program in satisfying overall Army requirements and, when required, provides for repair of materiel beyond the capability of general support maintenance organizations. (This function was formerly known as 5th echelon maintenance.)

Depot maintenance level organizations are stable and mobility is no problem. Equipment of extreme bulk and complexity can be used, if required. The high volume possible in these shops lends itself to effective use of assembly line techniques. This, in turn, permits use of relatively unskilled labor for the greater part of the workload, with a concentration of highly skilled specialists in key positions.

Depot maintenance is performed in shops in the continental United States or (for selected items) in shops established by

the overseas theater commander. However, most depot maintenance is located remotely from the theater of operation and performs services for several such theaters.

8-3.6 ARMY AIRCRAFT MAINTENANCE

Army aircraft maintenance differs from general maintenance described above in that it is restricted to three levels; Aviation Unit Maintenance (AVUM), Aviation Intermediate Support Maintenance (AVIM), and Depot Maintenance. In general, the skill level of maintenance personnel required to perform AVUM corresponds to that required to perform operator/crew and organizational maintenance. The skill level of maintenance personnel required to perform AVIM corresponds to that required to perform direct and general support maintenance. Depot maintenance for aircraft requires the same skill level as that for other Army maintenance.

SECTION II

HUMAN FACTORS

8-4 THE PROBLEM

World War II demonstrated that a military weapon is only as good as its operators and maintenance men. Machines and equipment performed at maximum capacity only if the operators and maintenance men did what they were supposed to do, in the proper sequence, and at the proper time.

Operators and maintenance men fail to do their jobs properly for a variety of reasons: fear and fatigue, hasty or inadequate training, and incompetency-a result of inadequate selection. They also fail because machines and equipment are designed without sufficient attention to the mental and physical capabilities of the men who operate or maintain them.

8-5 HUMAN FACTORS ENGINEERING

Human factors engineering is a factor which relates man's size, strength, and other capabilities to the necessary work. Failure to consider these factors will result in increased maintainability problems. Human factors engineering began when psychologists were called in to make critical investigations of, for example, physical limitations in aviation and behavior in naval combat information centers. Its goal was to provide designers with the probable characteristics of the individuals who would operate and maintain machines and equipment.

Human factors engineering today draws on psychology, physiology, physics, anthropology, and medicine, and requires close alliance between engineers and psychologists. Human factors engineers consider complex military equipment as man-machine systems, including as design considerations the capabilities and limitations of the man under various conditions.

To minimize diagnostic time, necessary human factors must be considered and equipment designed to facilitate quick, accurate, and positive action by the technician. These maintainability factors, some of which are also human factors, are considered in this chapter. This section discusses human body measurements

and human sensory capacities, and Section II presents recommendations for the selection and design of controls and displays.

8-6 HUMAN BODY MEASUREMENTS (ANTHROPOMETRY)

One important consideration in designing for maintainability is information on body measurements. This information is required in the earliest design stages to ensure that equipment will accommodate operators and maintenance men of various sizes and shapes. This section describes the sources of anthropometric measurements available to the designer indicating some of the types of information and giving examples of the more common measurements, with cautions as to their use.

8-6.1 SOURCES AND USE OF INFORMATION ON BODY MEASUREMENTS

The designer has two basic sources of information on body measurements: anthropometric surveys, in which measurements of a sample of the population have been made, or experiments under circumstances that simulate the conditions for which he is designing. Which of these sources or what combination is used depends on the availability of adequate anthropometric surveys and on the cost of experiments in both time and money.

Anthropometric data are usually presented in percentiles, ranges, and means (or medians). With information of this type, the designer, who usually will not be able to accommodate all possible sizes, can decide where to make the cutoff. He must, of course, design equipment so that all members of the population for which it is designed can operate and maintain it; but at the same time, he might have to inflict less efficient or less comfortable circumstances on a small percentage of the population, i.e., those individuals having extreme measurements.

8-6.2 TYPES OF BODY MEASUREMENTS

Both static and dynamic body measurements are important to the designer. Static measurements include everything from measurements of the most gross aspects of body size, such as stature, to measurements of the distance between the pupils of the eyes. The measurements required will depend on the particular equipment being designed. The more common static measurements, having received the most attention from anthropometrists, are most readily available and are the most reliable because of the large and numerous samples on which they are based.

Unlike static body dimensions, which are measured with the subject in rigid standardized positions, dynamic body measurements usually vary with body movements. Dynamic measurements include those made with the subjects in various working positions, and functional arm and leg reaches. Static dimensions corresponding to functional reaches would be anatomical arm and leg lengths. Dynamic dimensions in equipment design relate more to human performance than to human "fit".

8-6.3 EXAMPLES OF BODY MEASUREMENTS

Figures 8-2, 8-3 and 8-4 illustrate body dimensions to be considered in equipment design. Associated also with body dimensions is the application of force. The human being is so organized, muscularly, that he can exert force, with less fatigue, if the machine has been designed to fit his capabilities. The following conclusions on the application of force and the strength of body components should be of value to the designer:

(1) The amount of force that can be exerted is determined by the position of the body and the members applying the force, the direction of application, and the object to which it is applied.

(2) The greatest force is developed in pulling toward the body. (see Figure 8-5). Pull is greater from a sitting than from a standing position. A momentary pull can be as great as 250 lb, whereas the maximum steady pull is about 65 lb. (see Table 8-3).

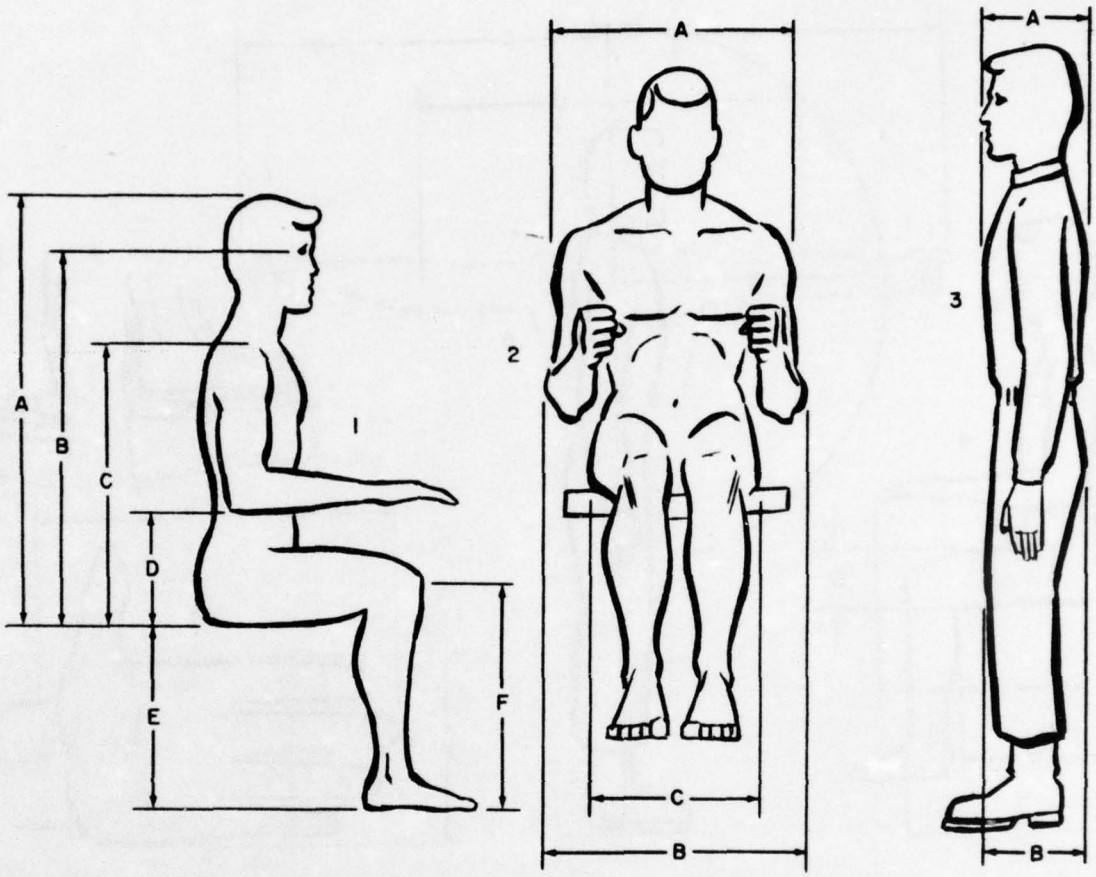
(3) The maximum force exertable increases with the use of the whole arm and shoulder, but using only the fingers requires the least energy per given amount of force applied.

(4) Push is greater than pull for side-to-side motion, with about 90 lb being the maximum.

(5) The maximum handgrip for a 25-year-old man is about 125 lb. Usually, the stronger hand can exert an average of 10 lb greater than the other.

(6) Arm strength reaches its maximum at about age 25, drops slightly between 30 and 40 and declines about 40% from age 30 to 65. Hand strength declines about 16.5% during the same period. These figures vary, however, depending upon conditions-a stamp collector's strength will not hold up like the strength of a man who performs manual labor.

Associated with force is weight lifting capacity. Figure 8-6 shows the maximum weight that can be lifted a given distance from the ground or floor. The curve is based on data from 19 male subjects whose average age was 21.6 yr, average weight was 161.2 lb, and average height was 69.5 in. They lifted objects



			SMALL MAN	LARGE MAN	LARGE MAN (heavy clothing)
HEIGHT		Height (stature)*	65.5	74.0	75.0
	1A	Sitting height (erect)*	33.5	38.0	40.5
	1B	Eye height (normal sitting) (internal canthus)	28.0	31.5	32.0
	1C	Buttock-shoulder height (acromial height)	22.7	26.5	27.0
	1D	Buttock-elbow height	7.4	10.8	10.8
	1E	Seat height (popliteal height)	16.7	19.2	19.2
	1F	Knee height	21.0	24.5	25.0
WEIGHT		Weight (pounds) (no equipment)	130.0	201.0	226.0
TRUNK	2A	Shoulder width (bi-deltoid)	16.5	20.0	26.0
	2B	Elbow width (bi-epicondylar-elbows)	15.3	20.3	31.5
	2C	Seat width	13.0	16.5	23.0
	3A	Chest depth	7.5	11.0	15.5
	3B	Abdominal depth	8.0	13.0	18.0

*Allow 2.6 inches for helmet.

Note: Small man represents the 5th percentile—only 5% of the population are smaller than the values given. Large man represents the 95th percentile—only 5% of the population are larger than the values given.

Figure 8-2. Body Dimensions for Use in Equipment Design

AD-A040 129 RCA GOVERNMENT SYSTEMS DIV BURLINGTON MASS AUTOMATED--ETC F/G 15/5
TEST ACCESSIBILITY DESIGN GUIDE FOR ARMY MECHANICAL, HYDRAULIC --ETC(U)
SEP 76 F W HOHN, K G HOPKINS, R C BLANCHARD DAAA25-75-C-0681
UNCLASSIFIED FA-FCF-10-76 NL

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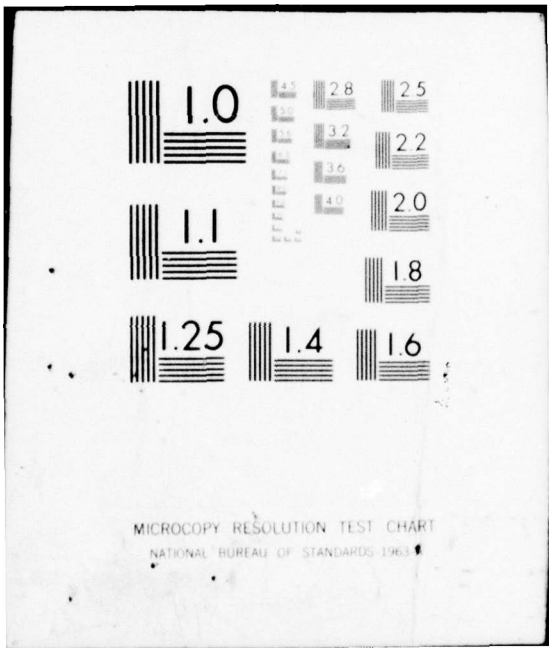
1.0
1.1
1.25
1.4
1.6
2.8
3.2
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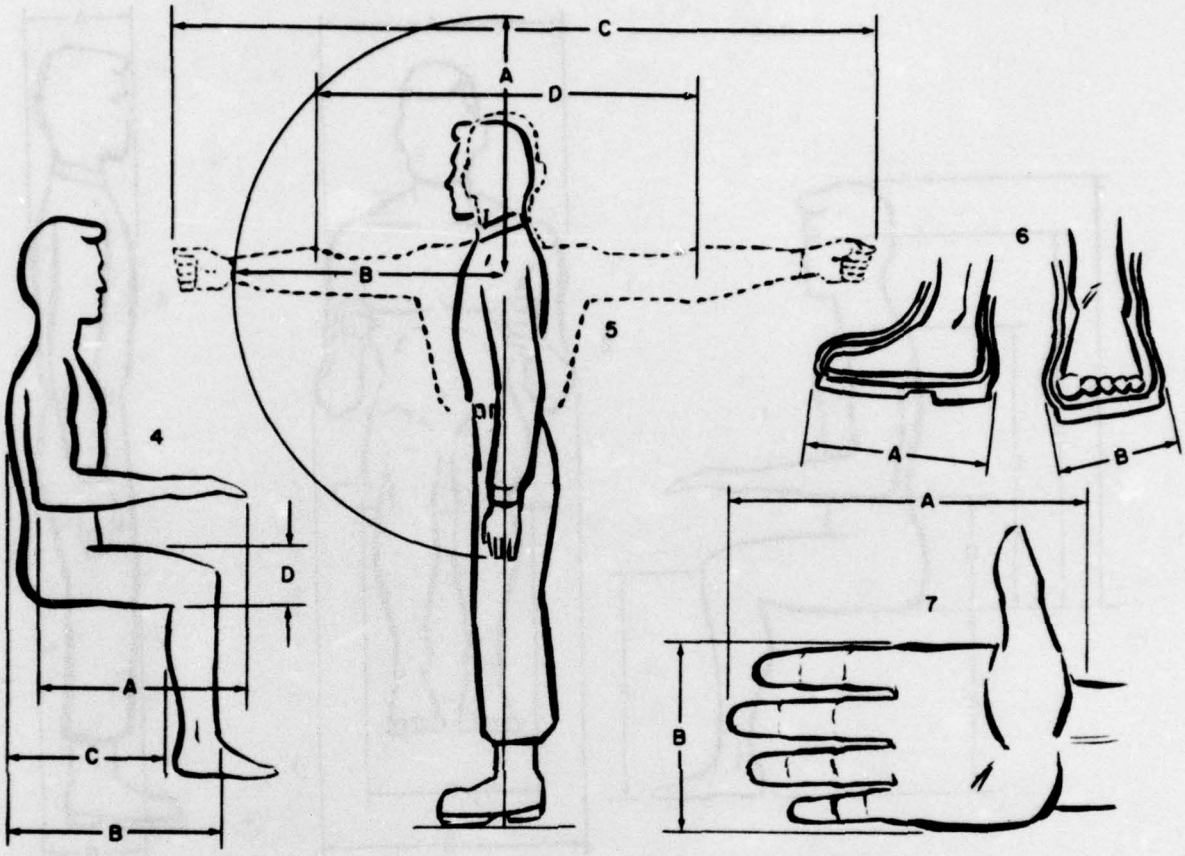
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963



			SMALL MAN	LARGE MAN	LARGE MAN (heavy clothing)
HEAD		Head length (front to back)**	7.2	8.2	11.5
		Head width (side to side)**	5.6	6.4	11.0
HAND	7A	Hand length	7.0	8.2	9.5
	7B	Hand width	3.2	3.8	5.5
ARM	4A	Elbow-finger length	17.3	20.1	21.3
THIGH	4B	Buttock-knee length	21.5	25.5	27.5
	4C	Seat length	17.5	20.5	20.5
	4D	Thigh clearance height (thigh thickness)	4.8	6.5	8.0
FOOT	6A	Foot length	11.0	12.7	15.3
	6B	Foot width	4.0	4.5	6.3
REACH	5A	Overhead reach (functional)	77.8	89.5	89.5
	5B	Arm reach—anterior (functional)	29.0	35.0	35.0
	5C	Arm span	65.9	75.6	78.0
	5D	Elbow span	34.0	39.0	41.0

**Helmet length = 12.0 inches, width = 10.3

Figure 8-2. Body Dimensions for Use in Equipment Design (cont)

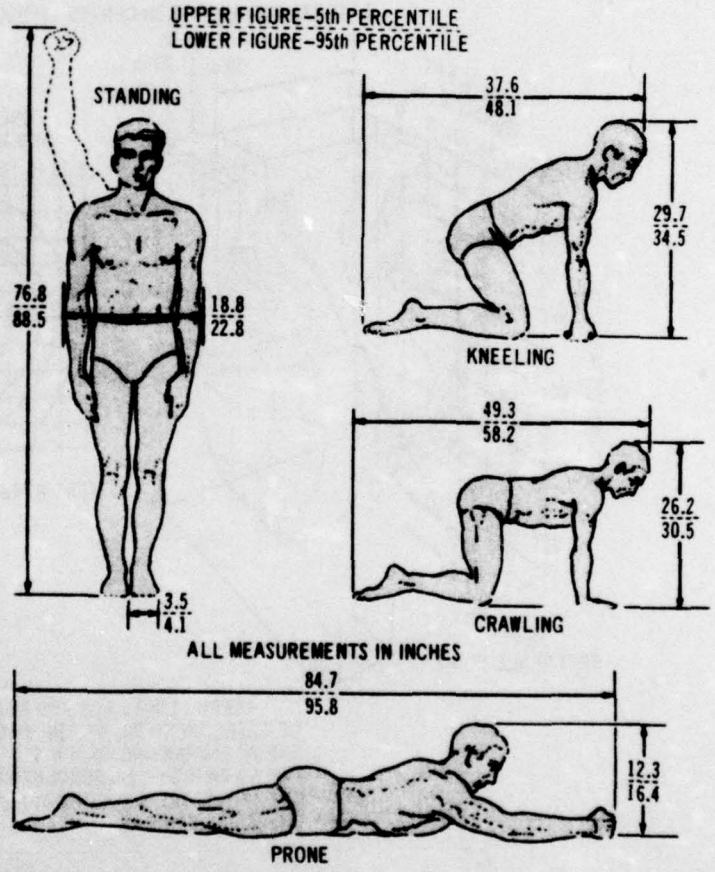
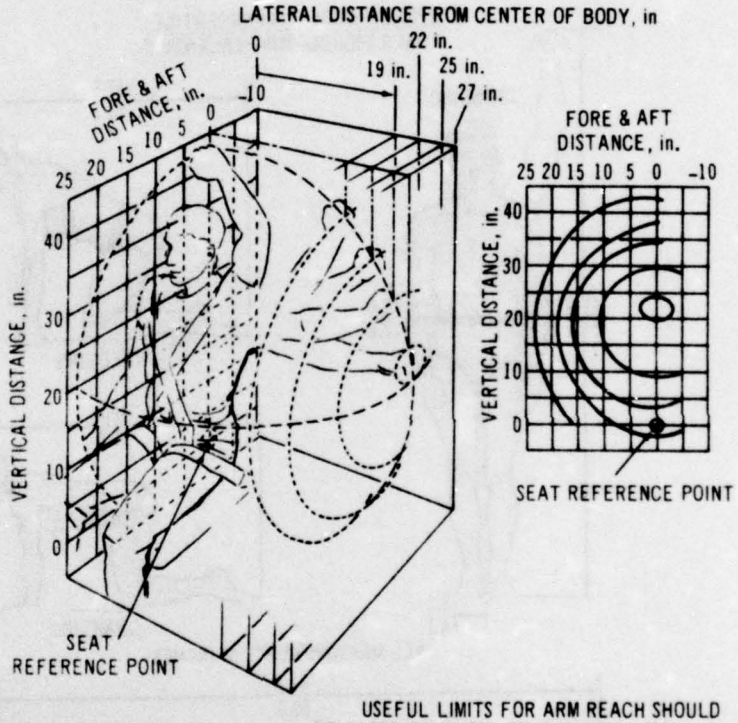


Figure 8-3. Human Body Measurements of Working Positions



USEFUL LIMITS FOR ARM REACH SHOULD BE BASED ON THOSE OF THE SMALL MAN. IN THE ACCOMPANYING GRAPH SELECTED DATA FOR A MAN WITH A 5th PERCENTILE ARM REACH ARE SHOWN. THE SUBJECT WAS RESTRICTED BY SHOULDER HARNESS.

Figure 8-4. Arm Reach Envelopes

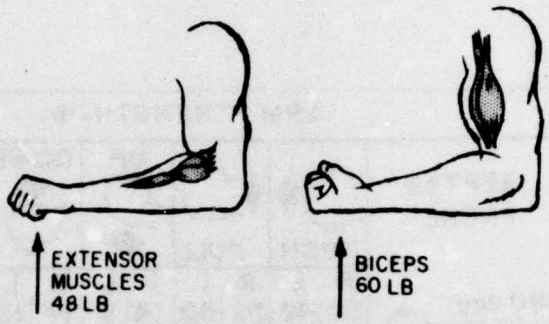


Figure 8-5. Amount of Force That Can be Exerted by the Arm in Two Positions

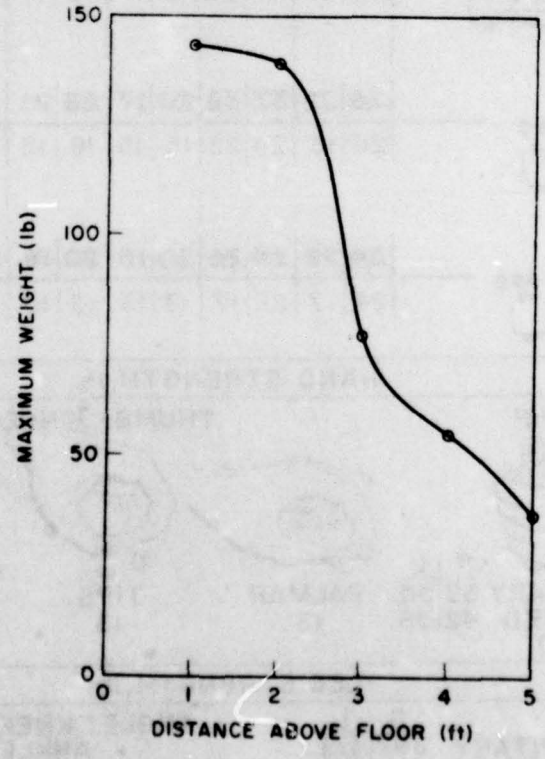


Figure 8-6. Maximum Weight Lifting Capacity

TABLE 8-3. DESIGN VALUES FOR MOTOR PERFORMANCE (MUSCLE STRENGTH)

ARM STRENGTH, lb.

SEATED PRONE	PUSH		PULL		UP		DOWN		IN		OUT	
	R	L	R	L	R	L	R	L	R	L	R	L
180 deg	50	42	52	50	14	9	17	13	20	13	14	8
	31	26	31	18	8	5	13	7	12	10	9	4
150 deg	42	30	56	42	18	15	20	18	20	15	15	8
	29	24	29	21	13	7	15	10	15	8	12	5
120 deg	38	26	42	34	24	17	26	21	22	20	15	10
	29	21	31	22	13	11	15	11	15	9	11	6
90 deg	36	22	37	32	20	17	26	21	18	16	16	10
	26	18	24	23	15	15	16	12	16	13	13	6
60 deg	34	22	24	26	20	15	20	18	20	17	17	12
	24	17	21	17	13	13	13	10	16	11	12	8

HAND STRENGTH, lb

GRIP

THUMB-FINGER GRASP

	R	L
MOMENTARY	59	55
SUSTAINED (1 min)	42	38

PALMAR 13

TIPS 13

LATERAL 15

LEG STRENGTH, lb

	R	L
MOMENTARY	387	413
SUSTAINED (2 min)	300	300

ANGLE: KNEE 111 deg ± 5 deg
ANKLE 60 deg ± 5 deg

of convenient size and shape and had unlimited room to do it in. Before a designer could use these figures, he would have to determine if the conditions for which he is designing would be the same.

8-7 HUMAN SENSORY CAPACITIES

The following data is presented to help the designer to a better understanding of the sensory capacities of the maintenance man as they apply to color coding, shape coding, parts identification, and noise.

8-7.1 SIGHT

Sight is stimulated by electromagnetic radiations of certain wavelengths, commonly called the visible portion of the electromagnetic spectrum. The various hues (parts of the spectrum), as seen by the eye, appear to differ in brightness. In daylight, for example, the eye is most sensitive to greenish-yellow light that has a wavelength of about 5500 angstrom units.

The eye also sees differently from different angles.

The limits of color vision are illustrated in Figure 8-7. One can perceive all colors while looking straight ahead. Color perception, however, begins to decrease as the viewing angle increases. As shown in the figure, green disappears at about 40° off the level view in the vertical plane, and red disappears at above 45°. Yellow and blue can be distinguished over a larger area. Therefore, if equipment has color-banded meters or warning lights of different colors that are in such a position as to be near the horizontal or vertical limits of color differentiation, the user will not be able to distinguish among the colors.

Color-weak people (so few people are absolutely color blind they can be ignored) will not see colors the way "normal" people do, and any color coding will be lost on them. Colors should, therefore, be selected which color-weak people do not confuse, such as yellow and blue, or color coding should be augmented with shape coding.

At night, or in poorly illuminated areas, color makes little difference, and at a distance, or if the point source is small (such as a small warning light), blue, green, yellow, and orange are indistinguishable: they will appear to be white. A further phenomenon of sight perception of light is apparent reversal of

color. When staring at a red or green light, for instance, and glancing away, the signal to the brain may reverse the color. This has caused accidents. Too much reliance should not be placed on color where critical operations may be performed by fatigued personnel. Whenever possible, red filters, having wavelengths longer than 6500 angstrom units should be used. If this is not possible, then warning lights, at least, should be as close to red as possible. Colors such as red-amber or reddish purple are satisfactory.

8-7.1.1 Glare

Glare is the most unwanted effect of illumination. It is controlled or mitigated through use of nonreflective coatings; by dull, minimally reflecting surfaces or panels; by proper placement of light sources; and by shielding. Overhead illumination should be shielded to about 45 deg to prevent direct glare.

Eyeglasses cause reflections unless the light source is 30 deg or more above the line of sight, 40 deg or more below, or outside 15 deg laterally from a straight line drawn from outside the corners of one's spectacles.

8-7.1.2 Cathode Ray Tube (CRT) and Other Light-emitting Displays

The following design recommendations apply to CRT:

1. Scope brightness should be variable between 0.05 and 10 foot lambert.
2. Phosphor excitation caused by ambient illumination should be eliminated.
3. Brightness ratio between CRT and other displays should not exceed 1:10.
4. Specular and diffuse reflections from surfaces of the tube, overlay, and filters should be eliminated.
5. Design should permit an observer to view the scope from as close as he may wish (see MIL-STD-1472).
6. Design should provide the appropriate degree of resolution.

Electroluminescent (EL) displays require a contrast ratio between figure and background of 20-30%. EL displays with appropriate dimming controls are extremely well suited for night flying. In bright sunlight some have a tendency to "wash out". Appropriate high-contrast construction, combined with antireflective coatings or filters, can meet the contrast and legibility requirements.

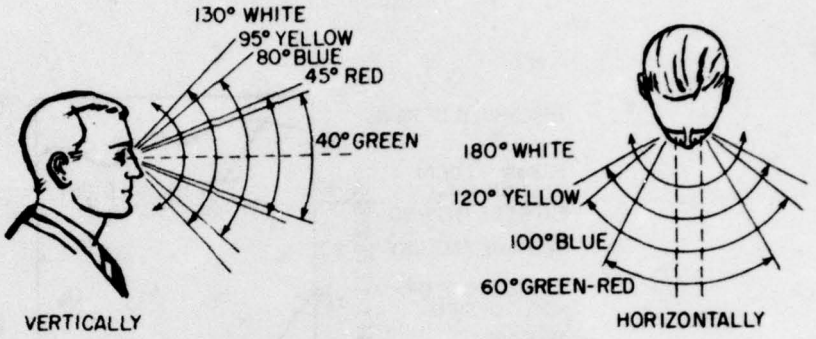


Figure 8-7. Approximate Limits of Normal Color Differentiation (Ref. 3)

8-7.2 TOUCH

As equipment becomes more complex, it is necessary that the maintenance man use all his senses most efficiently. Man's ability to interpret visual and auditory stimuli is closely associated with the sense of touch. The sensory cues received by the skin and muscles can be used to some degree to convey messages to the brain that relieve the eyes and ears of part of the load they would otherwise carry.

For example, control knob shapes can be easily recognized by touch alone. Many of these knob shapes could be adapted for use when the user must rely completely on his sense of touch, as, for instance, when a knob must be put in an out-of-the-way place.

8-7.3 NOISE

It is difficult to gage precisely the effects of noise on humans. Figure 8-8, illustrating the effects of sound intensities at various frequencies, may be used as a general guide.

Man's reaction to noise extends beyond the auditory system: it can contribute to such feelings as well-being, boredom, irritability, or fatigue. Work requiring a high degree of muscular coordination and precision, or intense concentration, may be adversely affected by noise. When sound exceeds a level of about 120 db, it begins to produce a physical sensation of feeling, or tickle, and at levels above 130 db it can become painful.

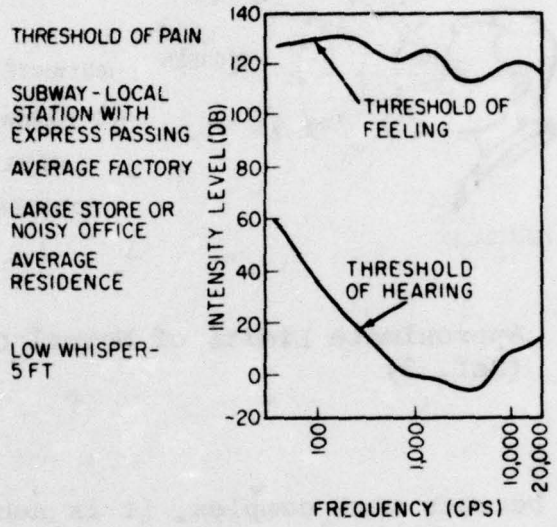


Figure 8-8. Sensations of Sound Intensities of Various Frequencies

In addition to affecting the performance of maintenance technicians in tasks not dependent upon auditory tasks, excessive noise can make oral communication ineffectual or impossible, and can damage hearing. Consequently, the interior noise levels in maintenance or control areas (vans, huts, etc.) in which communication of information, either direct or electrical, is critical, should not exceed the levels given in Table 8-4. These levels should permit reliable communications with raised voice at a distance of 3 to 4 ft. Equipment in operation or maintenance tasks shall not require personnel to be exposed to noise levels that exceed the maximum acceptable specified in Table 8-5.

The following recommendations should also be considered to reduce the effects of noise:

(1) In designing equipment which necessitates maintenance activities in the presence of extreme noise, reduce the amount of noise produced, where possible, by proper acoustical design, mufflers, soundproofing, and other devices.

(2) Keep sound levels in maintenance areas which require presence of the maintenance technician below 85 decibels (db re 0.0002 dyne/cm^2).

(3) Provide warnings to prevent unprotected maintenance personnel from entering areas with noise levels above 150 db, even

TABLE 8-4. MAXIMUM NOISE LEVELS FOR COMMUNICATION OF INFORMATION

Frequency Bands (Hz)	Maximum Level (db re 0.0002 microbar)
below 75	79
75-150	73
150-300	68
300-600	64
600-1200	62
1200-2400	60
2400-4800	58
4800-10000	57

for short periods. Exposure to such high noise levels may result in disorientation, nausea or vomiting. There is considerable variation in judgments of a single overall minimum noise level that is potentially harmful, i.e., which can cause permanent hearing loss. In general, levels above 100 db are not considered safe; levels below 90 db are not considered harmful.

Additional noise requirements including test requirements and measurement techniques are provided in MIL-STD-1474A (Ref. 2.).

8-7.4 VIBRATION AND MOTION

Vibration may be deterimental to the maintenance technician's performance of both mental and physical tasks. Large amplitude, low frequency vibrations contribute to motion sickness, headaches, fatigue, eye strain, interference with depth perception (depth perception fails at frequencies of 25-40 Hz and again at 60-90 Hz), and interference with the ability to read and interpret instruments. As the amplitude of vibration decreases and the frequency increases, these symptoms become less pronounced. However, vibration of low amplitude and high frequency can be fatiguing.

Some design recommendations to be considered for reducing the effects of vibration and motion are as follows:

(1) Design equipment to resist vibration and shock or to be isolated from such action by shock absorbers, cushioned mountings, springs, or fluid couplings.

(2) Where possible, consider the position of the operator and maintenance technician in the performance of their work on equipment that is subject to vibration.

(a) Seated personnel are most affected by vertical vibrations; prone personnel by horizontal vibrations.

(b) Use damping materials or cushioned seats to reduce vibration transmitted to a seated technician's body. Avoid vibrations of 3 to 4Hz, since this is the resonant frequency of the vertical trunk of a man when seated.

(3) For critical maintenance operations requiring letter or digit discrimination, ensure that the equipment containing the printed material is free from vibration produced by machinery.

(a) Avoid vibrations in excess of 0.08 mil amplitude. (1 mil = 10^{-3}in.).

(b) Where it is not possible to provide vibration-free displays, increase display size and/or illumination to improve speed and accuracy.

TABLE 8-5. MAXIMUM ACCEPTABLE NOISE LEVEL FOR ARMY EQUIPMENT

Frequency Bands (Hz)	Maximum Acceptable Noise Level (db re 0.0002 microbar)
below 75	120
75-150	115
150-300	109
300-600	101
600-1200	93
1200-2400	89
2400-4800	89
4800-9600	91

*Continuous Noise as Opposed to Impulse Noise

SECTION III

ATE-OPERATOR INTERFACE

8-8 THE NEED FOR COMMUNICATION

Test design for ATE must be effective in bridging the gap between the ATE machine and the operator. Until such time as mechanical, hydraulic and pneumatic equipment is designed for complete compatibility with automatic testing, there will continue to be operator intervention in the automated test process. One objective of test design is to minimize both the operator action required and the amount of communication between man and machine. A number of techniques have been developed which help achieve this objective. They are described below.

8-9 ROLE OF THE OPERATOR

The role of the operator on an ATE system should be limited to acting upon explicit directions contained in the operating procedure or communicated as a function of program execution. Whenever possible, the test program should communicate directly to the operator through ATE printouts or displays. References to technical manuals or other documents should be minimized to expedite testing. By restricting communication to simple direct instruction, special training for ATE operators can be reduced substantially. This is, of course, one of the basic objectives of ATE. It enables semi-skilled operators to monitor very complex tests under machine control. Relying on the operator for little else, except the ability to follow directions, places a burden on the test designer. Messages must be clear, concise, consistent and never subject to misinterpretation. The test designer must constantly be aware of the communication problem and project his thinking process into that of the most inexperienced operator.

Under no circumstances should the machine hang-up without giving the operator a course of action. This can usually be accomplished by special ATE indicators or by anticipating a potential hang-up and printing a message beforehand.

8-10 STANDARD/SHORT MESSAGES

One means for simplifying communication between the ATE and the operator is to standardize basic message statements in both language and format. Language standardization requires that words used repeatedly in automated test (such as replace, remove, insert, probe, and proceed) be defined in a more restrictive sense than is given in the dictionary. Many such words can lead to ambiguity if all dictionary definitions are allowed. For example, the message "replace A1" could mean to put back a previously removed module, to remove a defective module and substitute a spare, or to remove a suspect module and temporarily install a known good spare. Word definitions for ATE must be more exacting than normal usage, so a glossary of restricted definitions should be developed.

A number of very frequently used words can be defined in abbreviated form, if the length of instructions must be minimized.

8-11 FORMAT STANDARDIZATION

Format standardization deals with the arrangement of displayed or printed data. Information such as measured values should always be conveyed in a fixed-order format, such as test number, test value, units, high-low-go indication, and test sequence number. Rearranging such data in each different test program can be very confusing and misleading to the operator, even if the data is clearly stated. The use of tabulation, where multiple values must be communicated, helps clarify the presentation and at the same time keeps statements brief. It also has been found that the operator should be directed to perform only one action per individual message. If several steps are involved in a process, each step should be conveyed as a separate message. This procedure helps eliminate missed steps.

8-12 INTERPRETATION OF TEST DATA

Test results are conveyed to the operator by one of two possible means: display indicators (such as Nixie tubes or rear projection displays) and printouts (such as from a typewriter or line printer). During automatic testing, the speeds at which measurements are made make it impossible for the operator to react to measured value displays. Display of measurement data is only of value when the test is interrupted for manual action by the operator and during program validation when individual test performance must be verified. When a message references a

test value display, it is important that the values, in the message and on the test results display, be in a compatible format. It is poor practice to depend on the operator to scale or convert values in order to decide if a given value is within referenced limits.

When the ATE is used for qualification testing and a hard copy record of qualification data is printed, this data must first be converted and scaled to actual parameter values to permit correlation of printed data with non-ATE test data.

8-13 DATA REDUCTION

Although the capability exists in computer-controlled ATE, data reduction has generally been restricted to factory installations. The testing process itself seldom requires complex measured value processing. Most ATE decisions are based on single stimulus-single response measurements. Occasionally, sums and averages are taken, max and min points are evaluated, half points are established, and conversions are made. This is a form of data reduction, but a relatively simple one.

As ATE becomes more acceptable and equipped with computers more powerful than required for ATE control (i.e., with more memory, speed, and peripheral devices than required for the testing process), then more data correlation will be performed to evaluate large quantities of data relative to a particular unit or system being tested. This software will provide historical data and reliability data useful for establishing spare parts requirements. To date, this sophisticated interpretation of test results has been limited to factory production-line testing where ATE is even being used to select and batch incoming parts for optimum performance at the subassembly and assembly levels.

8-14 HANDLING REPAIR PROCEDURES

An ATE hardware/software package represents a sizeable investment. It is therefore of paramount importance that this package be used efficiently. It must test as many units per unit time as possible. Manual actions slow down the process excessively and therefore should be minimized. When an operator must make an adjustment on the unit being tested to obtain certain measureable outputs, the slowdown is tolerated because it is mandatory. It is not generally accepted practice, however, to stop the ATE during testing for repair processes. Rather, test programs should be written to detect and isolate related

faults and terminate. Fault data should be stored by the ATE (or printed sequentially on hard copy) through the testing process. Upon completion of testing, the required repair action should be stipulated via printed operator instructions and the unit being tested removed for repair. Thus, the ATE can test the next unit without delay.

8-15 HANDLING RETEST PROCEDURES

Retesting can apply to a specific parameter or to the complete unit being tested. Retesting of a specific parameter is recommended under either of two conditions:

(1) When a parameter is susceptible to noise transients peculiar to the testing process. The problem can be countered by automatic recycling of the test to verify the first result.

(2) When a manual adjustment is made by the operator under direction of a programmed instruction. Anything the operator does should be checked by the program, because the operator represents the least predictable link in the test process.

Retesting of a unit that has been tested is recommended standard operating procedure after any program-generated repair. The repair process could very well introduce new problems in the unit. Also, the possibility exists that the first run of the program did not identify all of the faults. Retest of a unit should be relatively fast since, if the repair was proper, only the end-to-end performance tests will be executed.

8-16 STORAGE AND RETRIEVAL

Part of the testing process must be concerned with obtaining the correct adapters and program tape for a given unit. Indexing schemes for control of these items in operational use should be established. Numbering systems and storage locations are important to the operational process. These items are essential operating tools and, if damaged or misplaced in any way, will impair the effectiveness of the ATE.

REFERENCES

1. MIL-STD-1472B, Human Engineering Design Criteria for Military Systems, Equipment and Facilities, 31 December 1974.

2. MIL-STD-1474A(MI), Noise Limits for Army Materiel, 3 March 1975.

CHAPTER 9
ENVIRONMENTAL AND OPERATIONAL CONDITIONS

9-1 GENERAL

Test points and transducers mounted on or designed as a part of Army systems, vehicles or aircraft must have a greater reliability and a greater stable lifetime than the systems which they are attached to or a part of. If this can be achieved, equipments will be seldom faulty and seldom repaired due to measurement devices. The test points and transducers, then, must be able to meet and surpass standards for the operation of equipments in the extremes of environment in which the Army must operate (refer to MIL-STD-210 for the full range of military environments). As an example, Army wheeled and tactical vehicles must be operable for 25,000 miles without field or depot maintenance under any extremes of climate and terrain. When the designer is considering transducers or test points for installation on such a vehicle, he cannot consider devices for such use unless they are qualified for all of the extremes which may be encountered. The following paragraphs describe the extremes of climate and terrain which must be considered when specifying test points and transducers to be installed on Army systems.

9-2 EFFECTS OF CLIMATE AND TERRAIN ON EQUIPMENT

When the patterns of climate, terrain and deterioration of materials are superimposed on the earth's surface, their boundaries coincide to a remarkable degree. There is a definite correlation between climate and deterioration of materials, and an even more definite correlation between terrain and problems of operation and maintenance resulting from deterioration of materials. A knowledge of these patterns of climate, therefore, is the first step in understanding problems associated with the deterioration of materials and the design, operation and maintenance of equipment.

9-2.1 TROPICAL CLIMATES

Tropical climates are generally defined as those in which the mean monthly temperature never goes below 64.9°F. The outstanding

common characteristics of tropical regions are high ambient temperatures and high humidity. These two conditions cause most problems of deterioration and of design, operation, and maintenance. The temperature extremes for equipment operating in the tropics is shown in the following chart:

CONDITION	TEMPERATURE EXTREMES	
Damp heat, high relative humidity, heavy seasonal rainfall, mold growth, destructive insects	Day: +40°C (104°F). Night: +20°C (+77°F). Exposed surfaces: +70°C (+158°F).	Humidity can approach saturation.

The following major problems are associated with tropical areas: corrosion of steel and copper alloys caused by electrolytic action; fungus growth on organic materials, such as canvas, felt, gasket materials, and sealing compounds, and even on the optical elements of fire-control equipment; deterioration through corrosion and fungus growth in insulation, generating and charging sets, demolition and mine-detection equipment, meters, dry cell batteries, storage batteries, cables, and a variety of lesser components. Termites may attack all wooden parts not impregnated with a repellent agent and are especially attracted by plywood bonded with a vegetable glue.

9-2.2 FUNGUS PROTECTION

Corrosion, rotting and weakening of materials can be caused by fungus. Materials inert to the growth of fungi should, therefore, be used whenever possible in the design of U.S. Army equipment.

In general, synthetic resins such as melamine, silicone, phenolic, fluorinated ethylenic polymers with inert fillers such as glass, mica, asbestos and certain metallic oxides provide good resistance to fungus growth. A list of materials generally considered fungus inert are listed in Table 9-1. Materials which are nonresistant to fungi are listed in Table 9-2. As shown in this table, not all rubber is fungus resistant, and antifungus coatings generally are impractical for this material. When fungus resistant rubber is needed, it should be so specified to insure that the manufacturer furnishes a suitable compound.

For specific requirements on the prevention of fungus growth, consult MIL-E-16400, MIL-M-11991, MIL-P-11268, and MIL-T-152.

TABLE 9-1. FUNGUS-INERT MATERIALS

Metals	Plastic materials using glass, mica or asbestos as a filler
Glass	Polyvinylchloride
Ceramics (steatite, glass-bonded mica)	Polytetrafluoro-ethylene
Mica	Monochlorotrifluoro-ethylene
Polyamide	Polyethylene
Cellulose acetate	Isocyanate
Rubber (natural or synthetic)	

TABLE 9-2. MATERIALS SUSCEPTIBLE TO FUNGUS FORMATION

Material	Fungus Proofing Specification	
Cork	MIL-T-12664	Treatment, mildew resistant, Class 1
Duck, Cotton	CCC-C-428	Duck, cotton, fire, water, weather, and mildew resistant
Felt, wool, Cattlehair	MIL-M-2312	Mildew-resistance and moisture-resistance treatment for felt, wool, cattlehair
Leather	O-L-164	Leather dressing; mildew preventive, Type I, Class A or B
Linen	MIL-T-3530	Treatment, mildew resistant, for thread and twine (Use Class 2)
Melamine resin compound with cellulose filler	MIL-V-173	Varnish, moisture and fungus resistant for the treatment of communications, electronic and associated electrical equipment
Phenolic resin compound with cellulose filler, and Plastic materials using cotton, line, or woodflour as a filler,	MIL-V-173 MIL-I-24092	Varnish, moisture and fungus resistant for the treatment of communications, electronic and associated electrical equipment

TABLE 9-2. MATERIALS SUSCEPTIBLE TO FUNGUS FORMATION (Continued)

Material	Fungus Proofing Specification	
notably the general purpose (Type PBG) grade		
Rope, natural fibre	T-T-616 (Avoid copper bearing agents.)	Rope; mildew resistant
Rubber (only certain compositions)	None	No treatment specification applies, but a grade of rubber meeting the fungus test requirement of MIL-I-631, Par. 4.6.16 will be fungus resistant, even though the title is "Insulation, Electrical Synthetic-Resin Composition, Nonrigid."
Thread, twine, natural fibre	MIL-T-3530	Treatment, mildew resistant, Class 2
Webbing, cotton	MIL-W-530	Webbing, textile, cotton, general purpose, natural or in colors
Wood	TT-W-571	Wood preservative; recommended treating practice
Adhesives	MIL-A-140	Adhesive, water-resistant, waterproof barrier-material
Insulation	MIL-I-631	Insulation, electrical, synthetic-resin composition, nonrigid
Fabrics, etc.	MIL-M-5658	Mildew proofing of fabrics, threads and cordages; copper processes for
Fabrics	MIL-M-46032	Mildew-resistant treatment (for fabrics) copper processes
Electrical Equipment	MIL-T-152	Treatment - moisture - and fungus-resistant, of communications, electronic, and associated electrical equipment
Fabrics, etc.	MIL-T-11293	Treatment - mildew-resistant, copper processes (for fabrics, thread, and cordage)
Rope	MIL-T-16070	Treatment - mildew-resistant, for rope
Wire, insulated	MIL-W-8777	Wire, electrical, copper, etc.
Wax	MIL-W-10885	Wax, impregnating, waterproofing, for laminated paper tubes, etc.
In addition, the microbial resistance of great numbers of items, formulations, components, etc., is governed by the following test methods or standards which are very widely used:		

TABLE 9-2. MATERIALS SUSCEPTIBLE TO FUNGUS FORMATION (Continued)

MIL-E-5272 Environmental Testing, aeronautical, etc.
MIL-STD-810 Environmental Test Methods
MIL-E-5400 Electronic equipment, aircraft, etc.
Fed. Test Method STD No. 191 Textile Test Methods
Fed. Test Method STD. No. 141 Paint, Varnish, Lacquer, etc.

The maintainability engineer should also realize when designing equipment to resist fungi, that, in general, it is not significant to know whether or not a specific kind of fungus is present in a given geographical location. But it is significant to know that any susceptible material is going to be degraded microbiologically wherever the temperature and humidity are suitable for microbial growth. It may or it may not be the same species of fungi in Florida, New Guinea, or Europe, but, regardless of location, there are fungi there which can do the damage.

9-2.3 CORROSION-RESISTANT MATERIALS

Materials selected should be corrosion resistant or should be protected by plating, painting, anodizing, or by some other surface treatment to resist corrosion. Surfaces required to be acid-proof should be given additional surface treatment. Metal surfaces not painted should be protected by other suitable means, e.g., encapsulating, and should be selected in accordance with MIL-S-5002. The use of any protective coating that will crack, chip or scale with age or extremes of climatic and environmental conditions should be avoided. Some good protective finishes for various metals are given in Table 9-3.

It is difficult to make definite comparisons of the corrosion-resistant properties of metals, since their resistance varies with the chemical environments. However, in vehicle design, the metals most commonly used for their corrosion resistant properties are:

Titanium	Chromium
Molybdenum alloys	Zinc
Stainless steel	Nickel
Pure Aluminum	Tin
Cadmium	Copper alloys

The aluminum and magnesium alloys are seriously degraded by corrosion and should be avoided.

TABLE 9-3. PROTECTIVE FINISHES FOR VARIOUS METALS

Material	Finish	Remarks
Aluminum alloy	Anodizing	An electrochemical-oxidation surface treatment for improving corrosion resistance; not an electroplating process. For riveted or welded assemblies, specify chromic-acid anodizing. Do not anodize parts with nonaluminum inserts.
	"Alrok"	Chemical-dip oxide treatment. Cheap. Inferior in abrasion and corrosion resistance to the anodizing process, but applicable to assemblies of aluminum and nonaluminum materials.
Copper and zinc alloys	Bright acid dip	Immersion of parts in acid solution. Clear lacquer applied to prevent tarnish.
Brass, bronze, zinc diecasting alloys	Brass, chrome, nickel, tin	As discussed under steel.
Magnesium alloy	Dichromate treatment	Corrosion-preventive dichromate dip. Yellow color.
Stainless steel	Passivating treatment	Nitric-acid immunizing dip.
Steel	Cadmium	Electroplate; dull white color, good corrosion resistance, easily scratched, good thread anti-seize. Poor wear and galling resistance.
	Chromium	Electroplate; excellent corrosion resistance and lustrous appearance. Relatively expensive. Specify hard chrome plate for exceptionally hard abrasion-resistant surface. Has low coefficient of friction. Used to some extent on nonferrous metals, particularly when die-cast. Chrome-plated objects usually receive a base electroplate of copper, then nickel, followed by chromium. Used for build-up of parts that are undersized. Do not use on parts with deep recesses.
	Blueing	Immersion of cleaned and polished steel into heated saltpeter or carbonaceous material. Part then rubbed with linseed oil. Cheap. Poor corrosion resistance.
	Silver plate	Electroplate; frosted appearance, buff to brighten. Tarnishes readily. Good bearing lining. For electrical contacts, reflectors.

TABLE 9-3. PROTECTIVE FINISHES FOR VARIOUS METALS (Continued)

Material	Finish	Remarks
Steel (cont)	Zinc plate	Dip in molten zinc (galvanizing) or electroplate of low-carbon or low-alloy steels. Low cost. Generally inferior to cadmium plate. Poor appearance and wear resistance. Electroplate has better adherence to base metal than hot-dip coating. For improving corrosion resistance, zinc plated parts are given special inhibiting treatments.
	Nickel plate	Electroplate; dull white. Does not protect steel from galvanic corrosion. If plating is broken, corrosion of base metal will be hastened. Finishes in dull white, polished, or black. Do not use on parts with deep recesses.
	Black oxide dip	Nonmetallic chemical black oxidizing treatment for steel, cast iron and wrought iron. Inferior to electroplate. No build-up. Suitable for parts with close dimensional requirements, such as gears, worms and guides. Poor abrasion resistance.
	Phosphate treatment	Nonmetallic chemical treatment for steel and iron products. Suitable for protection of internal surfaces of hollow parts. Small amount of surface build-up. Inferior to metallic electroplate. Poor abrasion resistance. Good point base.
	Tin plate	Hop dip or electroplate. Excellent corrosion resistance, but if broken will not protect steel from galvanic corrosion. Also used for copper, brass and bronze parts that must be soldered after plating. Tin plated parts can be severely worked and deformed without rupture of plating.
	Brass plate	Electroplate of copper and zinc. Applied to brass and steel parts where uniform appearance is desired. Applied to steel parts when bonding to rubber is desired.
	Copper plate	Electroplate applied preliminary to nickel or chrome plates. Also for parts to be brazed or protected against carburization. Tarnishes readily.

9-2.4 DISSIMILAR METALS

Dissimilar metals far apart in the galvanic series (Table 9-4) should not be joined directly together. If they must be used together, their joining surfaces should be separated by an insulating material, except if both surfaces are covered with the same protective coating.

TABLE 9-4. GALVANIC SERIES OF METALS AND ALLOYS

Anodic End (most easily corroded)	
Group	Metal
I	Magnesium Magnesium alloys
II	Zinc Galvanized iron or steel Aluminum (5058, 5052, 3004, 3003, 6063, 6053)
III	Cadmium Cadmium plated iron or steel Mild steel Wrought iron Cast iron Ni resist Lead-tin solders Lead Tin
IV	Chromium Admiralty brass Aluminum bronze Red brass Copper Silicon bronze Phosphor bronze Beryllium copper Nickel Inconel Monel Type 400 corrosion resisting steel Type 300 corrosion resisting steel Titanium
V	Silver Gold Platinum
Cathodic End (least susceptible to corrosion)	

For more detailed coverage of corrosion and corrosion protection of metals, see AMCP 706-311. Refer also to MIL-E-5400 and MIL-E-16400 for listings of acceptable corrosion resistant materials.

9-2.5 MOISTURE PROTECTION

The exclusion of moisture from equipment in the tropics considerably eases the maintenance problems. For example, Figure 9-1 illustrates the effect of moisture on the lowering of resistance of insulating materials. To help minimize such effects on insulating and other materials due to moisture, the following guidelines should be considered:

(1) Choose materials with low moisture absorption qualities wherever possible.

(2) Use hermetic sealing whenever possible. Make sure the sealing area is kept to a minimum to reduce danger of leakage.

(3) Where hermetic sealing is not possible, consider the use of gaskets and other sealing devices to keep out moisture. Make sure the sealing devices do not contribute to fungal activity, and detect and eliminate any "breathing" that may admit moisture.

(4) Consider impregnating or encapsulating materials with fungus-resistant hydrocarbon waxes and varnishes.

(5) Do not place corrodable metal parts in contact with treated materials. Glass and metal parts might support fungal growth and deposit corrosive waste products on the treated materials.

(6) When treated materials are used, make sure they do not contribute to corrosion or alter electrical or physical properties.

Where these methods are not practical, drain holes should be provided, and chassis and racks should be channeled to prevent moisture traps. Additional information on moisture protection can be supplied by the Prevention of Deterioration Center, National Research Council, 2101 Constitution Avenue, Washington, D.C. Refer also to MIL-E-5400 and MIL-E-16400 for listings of acceptable moisture resistant materials.

9-2.6 DESERT REGIONS

Desert regions occupy approximately 19 percent of the earth's land surface. The outstanding attribute of all deserts is dryness. Of the many definitions of a desert, a widely accepted one is an area with annual rainfall of less than 10 inches. Deserts are further characterized by a clear atmosphere and intense solar radiation, which results in temperatures as high as 126°F and ambient levels of illumination as high as 3000 foot-lamberts. This intense solar radiation combined with terrain which has a high reflectance can create high levels of glare. Other

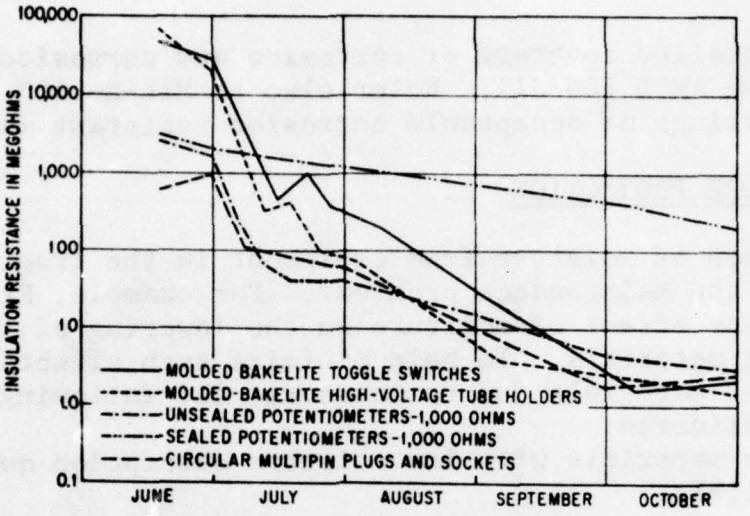


Figure 9-1. Drop in Insulation Resistance of Typical Electronic Components Exposed for 5 Months in Tropical Jungle

characteristic phenomena associated with deserts are atmospheric boil and mirages. Design for desert areas should also consider sand and dust which nearly always accompany dryness.

The high day temperatures, solar radiation, dust and sand, combined with sudden violent winds and large daily temperature fluctuations, may create many of the following maintenance problems: heat can lead to difficulties with electronic and electrical equipment, especially if these have been designed for moderate climates; materials such as waxes soften, lose strength, and melt; materials may loose mechanical or electrical properties because of prolonged exposure; fluids may lose viscosity; joints that would be adequate under most other conditions may leak. Heat can also cause the progressive deterioration of many types of seals found in transformers and capacitors. Capacitors of some type develop large and permanent changes in capacity when exposed to temperatures above 120°F.

The temperature extremes for electronic equipment operating in a desert environment is shown in the chart below.

The following factors should also be considered:

(1) Dry cells have a short life in hot environments, and, at temperatures above 95°F deteriorate rapidly.

(2) Wet batteries lose their charge readily.

(3) Tires wear out rapidly.

(4) Paint, varnish, and lacquer crack and blister.

Conditions	Temperature	
Dry heat, intense sunlight, sand dust, destructive insects	Day high: +60°C (+140° F), air +75°C (167° F), exposed ground Night low: -10°C (+14° F) Large daily variation: 40°C (72° F), average.	Relative humidity 5%

(5) The absorption of solar radiation by objects raises their temperatures well beyond the point where personnel can handle them without protection.
Test points, all types of switching equipment and gasoline engines are especially susceptible to damage by sand and dust. The sand and dust hazards are severe problems not only to finely machined or lubricated moving parts of light and heavy equipment, but also to personnel. Sand and dust get into almost every nook and cranny and in engines, instruments, and armament. Desert dust becomes airborne with only slight agitation and can remain suspended for hours so that personnel have difficulty in seeing and breathing. The most injurious effects of sand and dust result from their adherence to lubricated surfaces, but glass or plastic windows and goggles can be etched by sand particles driven by high winds.

9-2.7 ARCTIC REGIONS

In arctic regions, the mean temperatures for the warmest summer month is less than 50°F and for the coldest month, below 32°F. The extreme low temperatures of these regions change the physical properties of materials. Blowing snow, snow and ice loads, ice fog, and wind chill cause additional problems.

Problems associated with the operation and maintenance of equipment seem to be more numerous in arctic regions than elsewhere, and are caused mainly by driving snow and extreme low temperatures. The temperature extremes for equipment are shown in the following chart:

Conditions	Temperature
Low temperature, driving snow, icedust	Exposed arctic: -70°C (-94° F), extreme -40°C (-40° F), common Subarctic: -25°C (13° F), common

With the exception of inhabited areas, vehicle transportation is uncertain and hazardous because of the absence of roads. Travel from base to base is over rugged, snow-and-ice or tundracovered terrain. Tracked vehicles must be used for travel off the road. Drifting snow can enter a piece of equipment and either impede its operation, or melt and then refreeze inside as solid ice. Then, when the unit generates heat, the melted snow will cause short circuits, form rust, or rot organic materials.

The subzero temperatures may produce the following effects; volatility of fuels is reduced; waxes and protective compounds stiffen and crack; rubber, rubber compounds, plastics, and even metals in general lose their flexibility, become hard and brittle, and are less resistant to shock. At a temperature of -30°F, batteries are reduced in current capacity by 90 percent and will not take an adequate charge until warmed to 35°F. The variations in the capacitance, inductance, and resistance of electrical components and parts can become so great as to require readjustment of critical circuts.

9-2.8 SUMMARY OF ENVIRONMENTAL EFFECTS

The environmental conditions under which unsheltered equipment should be designed for satisfactory operation are given in Table 9-5. A summary of the major environmental effects is given in Table 9-6.

9-3 HYDRAULIC FLUID CORROSIVENESS

In its broadest meaning, corrosion refers to the deterioration of a metallic surface by chemical or electrochemical action; a familiar example is the rusting of iron. The corrosiveness of a hydraulic fluid relates to its tendency to promote or encourage corrosion in a hydraulic system. It is obviously desirable to maintain the corrosiveness of a hydraulic fluid at as low a level as possible.

The corrosiveness of a hydraulic fluid, usually at its lowest value when the fluid is new and unused, can be affected by a number of variables such as temperature, load, moisture, chemical nature of the liquid, oxidation stability, the type and amount of degradation products formed, the dispersion of the products in the system, and numerous other variables. Only a few of these variables, however, are parameters of the liquid. Variables such as temperature, load, and exposure to moisture, etc., are system mechanical factors and can - through proper system design and the

TABLE 9-5. ENVIRONMENTAL REQUIREMENTS FOR UNSHELTERED EQUIPMENT

Environment	Environmental Limits
Temperature	
Standard area	
Operating	-29 to 52°C (-20 to 125°F)
Nonoperating	-54 to 54°C (-65 to 130°F)
Cold weather area	
Operating	-40°C (-40°F) if operator is unsheltered
Operating	-54°C (-65°F) if operator is sheltered
Nonoperating	-62°C (-80°F) for 3 days and achieve rated capacity after 30 minutes preheating and warm-up
Desert and tropical areas	
Operating	52°C (125°F)
Nonoperating	71°C (160°F) for 4 hours per day indefinitely
Humidity	
Operating	Up to 100% at 37°C (100°F) including condensation
Nonoperating	Up to 100% including condensation
Solar Radiation	Endure a solar intensity of 360 BTU per square foot, per hour for a period of 4 hours at 52°C (125°F)
Wind	Withstand wind pressures up to 30 pounds per square foot of projected surface, either empty or under load
Barometer pressure	
Operating	From 30 to 16.8 inches of mercury (0-15,000 ft)
Nonoperating	From 30 to 5.54 inches of mercury (0-40,000 ft)

TABLE 9-6. SUMMARY OF MAJOR ENVIRONMENTAL EFFECTS

Environment	Principal Effects	Typical Failures Induced
High temperature	Thermal aging:	Insulation failure
	Oxidation	Alteration of electrical properties
	Structural change	
	Chemical reaction	
	Softening, melting and sublimation	Structural failure
	Viscosity reduction and evaporation	Loss of lubrication properties
	Physical expansion	Structural failure
		Increased mechanical stress
		Increased wear on moving parts
Low temperature	Increased viscosity and solidification	Loss of lubrication properties
	Ice formation	Alteration of electrical properties
	Embrittlement	Loss of mechanical strength
		Cracking, fracture
	Physical contraction	Structural failure
		Increased wear on moving parts
High relative humidity	Moisture absorption	Swelling, rupture of container
		Physical breakdown
		Loss of electrical strength
	Chemical reaction:	Loss of mechanical strength
	Corrosion	Interference with function
	Electrolysis	Loss of electrical properties
		Increased conductivity of insulators
Low relative humidity	Desiccation:	Loss of mechanical strength
	Embrittlement	Structural collapse
	Granulation	Alteration of electrical properties
		"Dusting"
High pressure	Compression	Structural collapse
		Penetration of sealing
		Interference with function

TABLE 9-6. SUMMARY OF MAJOR ENVIRONMENTAL EFFECTS (Continued)

Environment	Principal Effects	Typical Failures Induced
Low pressure	Expansion	Fracture of container
		Explosive expansion
	Outgassing	Alteration of electrical properties
		Loss of mechanical strength
	Reduced dielectric strength of air	Insulation breakdown and arcover
		Corona and ozone formation
Solar radiation	Actinic and physicochemical reactions:	Surface deterioration
		Alteration of electrical properties
	Embrittlement	Discoloration of Materials
		Ozone formation
Sand and dust	Abrasion	Increased wear
	Clogging	Interference with function
		Alteration of electrical properties
Salt spray	Chemical reactions:	Increased wear
	Corrosion	Loss of mechanical strength
		Alteration of electrical properties
		Interference with function
	Electrolysis	Surface deterioration
		Structural weakening
		Increased conductivity
Wind	Force application	Structural collapse
		Interference with function
		Loss of mechanical strength
	Deposition of materials	Mechanical interference and clogging
		Abrasion accelerated
	Heat loss (low velocity)	Accelerates low-temperature effects
	Heat gain (high velocity)	Accelerates high-temperature effects
Rain	Physical stress	Structural collapse
	Water absorption and immersion	Increase in weight
		Aids heat removal

TABLE 9-6. SUMMARY OF MAJOR ENVIRONMENTAL EFFECTS (Continued)

Environment	Principal Effects	Typical Failures Induced
Rain (cont)	Water absorption and immersion (cont)	Electrical failure
		Structural weakening
	Erosion	Removes protective coatings
		Structural weakening
		Surface deterioration
	Corrosion	Enhances chemical reactions
Water immersion	Corrosion of metals	Structural weakness, seizure of parts, contamination of products
	Chemical deterioration	Dissolving out and changing of materials
	High pressures (13 lb at 30 ft depth)	Mechanical damage
Insects and bacteria	Penetration into equipment	Blockage of small parts, meters, etc.
	Nibbling by termites	Damage to plastic cables or other organic insulating materials, causing shorts
Fungi	Growth of molds, hyphae	Damage to optical equipment; leakage paths in high impedance circuits; blockage of small parts, meters, etc.; breakdown of mechanical strength of all organic materials
Temperature shock	Mechanical stress	Structural collapse or weakening
		Seal damage
High speed particles (nuclear irradiation)	Heating	Thermal aging
		Oxidation
	Transmutation and ionization	Alteration of chemical, physical and electrical properties
		Production of gases and secondary particles
Ozone	Chemical reactions:	Rapid oxidation
	Crazing, cracking	Alteration of electrical properties
	Embrittlement	Loss of mechanical strength
	Granulation	Interference with function
	Reduced dielectric strength of air	Insulation breakdown and arcover
Explosive decompression	Severe mechanical stress	Rupture and cracking
		Structural collapse

TABLE 9-6. SUMMARY OF MAJOR ENVIRONMENTAL EFFECTS (Continued)

Environment	Principal Effects	Typical Failures Induced
Dissociated gases	Chemical reactions;	Alteration of physical and electrical properties
	Contamination	
	Reduced dielectric strength	Insulation breakdown and arcover
Acceleration	Mechanical stress	Structural collapse
Vibration	Mechanical stress	Loss of mechanical strength
		Interference with function
		Increased wear
	Fatigue	Structural collapse
Magnetic fields	Induced magnetization	Interference with function
		Alteration of electrical properties
		Induced heating

use of the correct hydraulic fluid - be controlled within a range of acceptable limits. Fluid parameters - those variables that relate to the corrosiveness of the liquid such as chemical nature and oxidation stability - are fundamental properties of the liquid and cannot be varied except by the use of additives.

9-3.1 CHEMICAL CORROSION

Purely chemical corrosion is probably the most prevalent type of corrosion found to exist in fluid power systems. Although starting rapidly, it may often become low as soon as a layer of corrosion products has been formed on the metallic surface. If, however, the layer or corrosion products are being continually cracked or removed, corrosion will continue at its original rate. Of the various types of corrosion, the two that occur in most systems are oxidation and acidic corrosion. Oxidation is limited to the surface of metals and its results are exhibited by an accumulation of metal oxides. Acidic corrosion refers to the deterioration of the metallic surface caused by the metal actually being dissolved by acids and washed away, leaving a pitted surface.

Rusting is the oxidation of the base iron in the metal structures. The oxidation is usually catalyzed or increased by the presence of dissolved air and water in the system liquid. Prevention of oxidation is theoretically the easiest corrosion action to control. Simple exclusion of air and moisture from the system could eliminate rusting. However, because it is almost impossible to completely exclude all air and moisture from a hydraulic system, numerous additives are used as oxidation and corrosion inhibitors.

Oxidation of the hydraulic fluids while in use produces acid-type products which can rapidly increase the corrosiveness of the fluid. It is, therefore, desirable to maintain a high level of oxidation stability in the fluid. There are inhibitors which can reduce the acid corrosion tendencies of a hydraulic fluid.

The corrosive tendencies of a liquid are frequently increased by the presence of various metals which act as catalysts. Copper is a common example. Many liquids become much more corrosive than usual in the presence of copper; thus several of the test procedures for determining corrosion properties of liquids make use of a copper catalyst. The problem is basically one of liquid-metal compatibility.

9-3.2 ELECTROCHEMICAL CORROSION

While almost any chemical reaction can be called electrochemical, the term is usually limited to cases with spatially separated anodic and cathodic areas, so that corrosion is accomplished by electric current flowing for a perceptible distance through the metal. It is not necessary to have two metals for electrochemical corrosion. All that is needed is the metal, a material of a different electric potential and a conductance path between them. A corrosion product or liquid can serve as the source of the second electric potential.

Galvanic corrosion is probably the most common form of electrochemical corrosion. Galvanic corrosion occurs when dissimilar metals, in electrical contact with each other, are exposed to an electrolyte. A current, called a galvanic current, then flows from one metal to the other. Galvanic corrosion is that part of the resulting corrosion of the anodic (positive) member of the metal couple.

Many hydraulic fluids are not good electrolytes when new and do not promote galvanic or electrochemical corrosion. However,

contaminants that enter or form in the fluid during use, and some types of additives, may give the liquid electrolytic properties. Several precautions can be taken to stop or reduce the electrochemical action of the galvanic couple and reduce the corrosion; e.g., using similar metals, insulating the metals, or eliminating the electrolyte. These steps are frequently impractical and other precautions, such as using corrosion inhibitors, must be taken.

9-3.3 HYDRAULIC FLUID CORROSIVENESS TESTS

Numerous test methods have been proposed and developed for determining the corrosive properties of liquids. While most of the tests are universal in that they are designed for any type of liquid or lubricant, certain tests have been developed specifically for gear lubricants, for hydraulic fluids, or for other special liquids. These corrosiveness tests fall into three general categories: (1) metal-liquid tests where a metal surface is exposed to the liquid for a given length of time at given conditions, (2) fog or humidity cabinet tests where a strip of metal is coated with the liquid and exposed to extremely humid conditions for a predetermined period of time, and (3) engine tests where the liquid is tested in a gear box of an engine under controlled conditions. Reference 2 explains the tests in all three categories.

9-4 HYDRAULIC FLUID COMPATIBILITY

A hydraulic fluid must be compatible with the materials used in the hydraulic system, including metals, plastics, surface coatings, elastomers, and occasionally other materials of construction, lubricants, and other hydraulic fluids. If the hydraulic fluid in any way attacks, destroys, dissolves, or changes any part of the hydraulic system; the system may become inoperable and, conversely, any changes in the hydraulic fluid caused by interaction with the system materials can also cause system malfunction. Therefore, compatibility of a hydraulic fluid with the system means that the fluid should not attack the system, and the system should not attack the fluid.

Compatibility must be considered from several points of view. First, there should be compatibility of the hydraulic fluid with the hydraulic system. Of primary concern is compatibility with the metals of construction and the elastomers used for sealing. Also important are the various surface treatments of materials in or near the system, such as paints and special surface finishes. Second there should be compatibility of the hydraulic fluid with the system environment. Breakage, leakage, and spillage all too frequently bring the hydraulic fluid into contact with its immediate environment. Of concern here are paints, fabric or

plastic linings or covers, insulation and electrical wiring, and structural materials used near the hydraulic system. Third, there should be compatibility of the hydraulic fluid with other liquids and lubricants it may contact. Of concern here is additive susceptibility, use of substitute hydraulic fluids, and choices of lubricants for the system. Each of these factors must be examined individually and in combination for compatibility with the hydraulic fluid.

There is often difficulty in determining the compatibility of a hydraulic fluid with the hydraulic system. Because of the wide range of operating conditions and the large number of possible materials, there have been very few Federal or ASTM test procedures developed for determining compatibility. When a question of compatibility arises, the normal test procedure is to expose the material in question to the hydraulic fluid (under simulated service conditions, if possible) and determine changes in the material. One unique facet of this type of procedure is that emphasis is placed on the material and not on the hydraulic fluid. The question then arises whether compatibility is a property of the hydraulic fluid or of the material. Because compatibility is an interaction between a hydraulic fluid and enumerable other materials, hydraulic fluid specifications usually include a limited number of requirements on compatibility. The most frequently encountered examples are rubber swelling requirements. Also, most hydraulic fluid specifications require that all liquids qualified under the specification be compatible with each other.

9-4.1 HYDRAULIC FLUID COMPATIBILITY WITH METALS

Compatibility of a hydraulic fluid with the metals used in a hydraulic system is most important. Care must be taken that system design excludes all metals that are damaged by the liquid or that degrade the liquid. Liquid-metal compatibility, in its strictest sense, includes only chemical interrelationships; however, the topic is broadened here to include any influence the hydraulic fluid may have on metal fatigue and cavitation.

It is common practice to use copper, silver, bronze, aluminum, steel, magnesium, and many other metals as structural materials although some metals, especially copper, act as catalysts after degradation starts in some petroleum liquids. However, many of the newer synthetic fluids may not be compatible with one or more of the conventional metals. For example, diester fluids such as the turbine engine oil MIL-L-7808 are affected by copper and its alloys above 200°F. At 500°F, which is 200°F above its maximum usable temperature, such a diester still has a life of 8 to 12 hours

in a sealed system. If a small piece of brass or copper is present, the fluid is reduced to a thick, black, molasses-like substance of high acidity and foul odor within an hour.

Liquid-metal compatibility may be measured by a number of tests. These techniques usually involve exposing the metal to the liquid under a variety of conditions and determining any changes in the liquid or the metals. Many of the tests mentioned in the paragraphs on Chemical Stability (Reference 2) or Corrosiveness (paragraph 9-3) are quite useful and have been widely used.

Difficulty often arises in attempting to relate test conditions to actual service conditions. Many conditions that occur in service cannot be anticipated and incorporated into the test. One example is galvanic corrosion. Hydraulic fluids may become electrolytes between dissimilar metals during use and cause considerable corrosion. It then becomes necessary to study metal-to-metal couples in the presence of candidate hydraulic fluids. Most fluid manufacturers have conducted extensive research into the liquid-metal compatibility of their products and data are available to prospective purchasers. In most cases, hydraulic fluids are compatible with all common metals used in construction of hydraulic systems, and the fluid manufacturers only provide data for those instances where the fluid and metal are not compatible.

REFERENCES

1. AMCP 706-134, Engineering Design Handbook, Maintainability Design Guide.

2. AMCP 706-123, Engineering Design Handbook, Hydraulic Fluids.

CHAPTER 10
THE IMPORTANCE OF PHYSICAL ACCESSIBILITY

10-1 GENERAL

Accessibility often is limited because of the necessity of meeting physical design constraints imposed upon the system to assure performance and other design requirements. The specific physical design requirements affecting accessibility are weight, volume, repair/work space and structural integrity. These characteristics, in turn, affect the density of equipment installations and installation locations.

Rapid and easy access to equipment is required to perform servicing and preventive and corrective maintenance within a reasonable amount of time and effort. Therefore, accessibility priorities must be established during the preliminary design phase to insure that special design attention is focused upon access to critical equipment and interfaces. The factors that should be considered when establishing these priorities are:

(1) Frequently performed scheduled maintenance. Daily and weekly preventive maintenance inspection tasks account for a significant percentage of all maintenance time expenditures at the organizational level. Providing ready access for performing inspection and servicing tasks facilitates the performance of these tasks and reduces the maintenance load.

(2) Frequently performed corrective maintenance. Equipment with a relatively high failure rate should be located in readily accessible positions within the equipment.

(3) Infrequently performed scheduled and unscheduled maintenance tasks. Access to support these tasks is given the lowest priority.

The developing design should be monitored to assure that access requirements are met. Design features that aid accessibility are:

(1) Location of access doors at heights where they may be opened and closed readily at normal working levels without auxiliary stands or other equipment. All high-priority equipment and interfaces should have this characteristic.

(2) Incorporation of built-in aids such as walkways, work surfaces and telescoping ladders that afford access to work areas that

are out of normal reach and otherwise would require maintenance stands or other equipment to reach them.

(3) Location of inspection gauges, meters, maintenance panels, high failure rate equipment, fluid fill ports and support equipment behind readily actuated doors.

(4) Provision of inspection windows or directly accessible indicators for determining fluid levels, pressures, and filter status.

(5) Provision of hinged doors in lieu of panels requiring complete removal to obtain access.

(6) Placement of access doors within larger structural doors when it is necessary to attain quick access to facilitate high-priority maintenance tasks.

(7) Use of rack and panel installations. This type of installation is particularly advantageous because the need for access to disconnect and connect the equipment is eliminated or reduced substantially.

(8) Location of equipment connectors, metering devices, controls and indicators on the most accessible equipment surface.

(9) Provision of mechanical stops or braces to hold access doors open.

(10) Avoidance of locations (for high-priority access) that feature proximity to bulkheads, rods, wire harnesses, pneumatic and hydraulic lines, shelves, structural members or other potential sources of access interference.

(11) Provision of equipment bays wherein arrays of subsystem equipment are installed by rack and panel methods. The equipment installed in such bays should be components of the same subsystem and interfacing subsystems in order to facilitate maintenance.

(12) Provision of test points and adjustment controls that are accessible directly without requiring case covers or panels to be removed.

(13) Use of minimum quantities of captive quick release fasteners to secure case covers and panels.

(14) Location of subassemblies with high failure rates in a manner that assures immediate access for maintenance after covers or panels are removed.

(15) Packaging of meters and controls in modules to allow their removal from equipment without requiring cover or panel removal.

(16) Provision of direct access to mounting screws and bolts, and incorporation of tool guides to them when visual access is limited or a hazardous condition exists.

(17) Avoidance of the use of cordwood construction and installation techniques.

(18) Avoidance of box-within-a-box designs except as they are necessary to permit pressurization or provide electromagnetic interference protection.

10-2 ACCESS FOR MECHANICAL INSPECTION, REPAIR AND TESTING

The following checklists provide a comprehensive means of analyzing a mechanical, hydraulic or pneumatic requirement design for serviceability and accessibility:

10-2.1 ACCESSIBILITY CHECKLIST

Consideration must be given to national and international standards for accessibility. This is important in Military Application of Commercial Items (MACI). In addition to any requirements imposed by the contract and military specifications and standards, the following should be considered for all new equipment designs:

(1) Is optimum accessibility provided in all equipment and components requiring maintenance, inspection, removal, or replacement?

(2) Is a transparent window or quick-opening metal cover used for visual inspection accesses?

(3) Are access openings without covers used where they are not likely to degrade performance?

(4) Is a hinged door used where physical access is required (instead of a cover plate held in place by screws or other fasteners)?

(5) If lack of available space for opening the access prevents use of a hinged opening, is a cover plate with captive quick-opening fasteners used?

(6) If a screw-fastened access plate is used, are no more than 4 screws used?

(7) On hinged access doors, is the hinge placed on the bottom or is a prop provided so that the door will stay open without being held if unfastened in a normal installation?

(8) Are parts located so that other parts which are difficult to remove do not prevent access to them?

(9) Are components placed so that there is sufficient space to use test probes, soldering irons, and other required tools without difficulty.

(10) Are units placed so that structural members do not prevent access to them?

(11) Are components placed so that all throw-away assemblies or parts are accessible without removal of other components?

(12) Is equipment designed so that it is not necessary to remove any assembly from a major component to troubleshoot to that assembly?

(13) Can screwdriver operated controls be adjusted with the handle clear of any obstructions?

(14) Are units laid out so maintenance technicians are not required to retrace their movements during equipment checking?

(15) Is enough access room provided for tasks which necessitate the insertion of two hands and two arms through the access?

(16) If the maintenance technician must be able to see what he is doing inside the equipment, does the access provide enough room for the technician's hands or arms and still provide for an adequate view of what he is to do?

(17) Are irregular extensions, such as bolts, tables, and hoses easy to remove before the unit is handled?

(18) Are access doors made in whatever shape is necessary to permit passage of components and implements which must pass through?

(19) Are units removable from the installation along a straight or moderately curved line?

(20) Are heavy units (more than about 25 pounds) installed within normal reach of a technician for purposes of replacement?

(21) Are rests or stands provided on which units can be set to prevent damage to delicate parts?

(22) Are provisions made for support of units while they are being removed or installed?

(23) Is split-line design utilized wherever possible and necessary?

(24) Are access points individually labeled so they can be easily identified with nomenclature in the job instructions and maintenance manuals?

(25) Are accesses labeled to indicate what can be reached through this point (label on cover or close thereto)?

(26) Are accesses labeled to indicate what auxiliary equipment is needed for service, checking, etc. at this point?

(27) Are accesses labeled to specify the frequency for maintenance either by calendar or operating time?

(28) Are access openings free of sharp edges or projections which could injure the technican or snag clothing?

(29) Are parts which require access from two or more openings marked to so indicate in order to avoid delay and/or damage by trying to repair or remove through only one access? Are double openings of this type avoided wherever possible?

(30) Are human strength limits considered in designing all devices which must be carried, lifted, pulled, pushed, and turned?

(31) Are environmental factors (cold weather, darkness, etc.) considered in design and location of all manipulatable items of equipment?

(32) Label each access with the items accessible through it as well as the auxiliary equipment to be used at the access.

(33) Label each access with a unique number, letter, or other symbol designation so that each one can be clearly identified in job instructions and maintenance manuals.

(34) Provide an indication of the position for insertion of components and connectors through small accesses. Use matching stripes, dots, or arrows on the cabinet and on the component to be inserted. Where space permits, a drawing of the pin position may be used.

(35) Locate accesses to prevent contact of parts of the body placed into the access with hot or extremely cold components toxic substances, moving parts, electrical current, or sharp edges. Also, ensure that the access location does not require the maintenance technician to assume postures that might cause body parts outside of the access to come in contact with these danger sources.

(36) Use a locking device on large access doors which might fall shut and cause damage or injury.

(37) Round the edges of access openings or provide a rubber, fiber, or plastic covering if sharp edges could injure the technician's hands or arms.

(38) Provide visual access for maintenance operations which must be performed in areas where there is danger from nearby electrical circuits. If visual access cannot be provided, thoroughly insulate exposed wires and provide location diagrams as a guide to the maintenance technician. Where adjustment points are located near high voltage, provide screwdriver guides to these adjustments to prevent contact with dangerous voltages.

(39) Provide safety interlocks on accesses leading to equipment with high voltage. If the equipment circuit must be on during maintenance, provide a cheater switch that automatically resets when the access is closed.

(40) Provide self-sealing fuel, water-alcohol and oil tanks with an access door of such size that the entire interior of the tank is available for inspection, cleaning, or other maintenance without removing the tank.

(41) Locate hydraulic reservoirs so they are visually accessible for refilling. If the technician cannot see the fluid level, the hydraulic fluid may overflow and damage nearby components.

(42) In using split bearings, optimize accessibility by making the plane of the split of the bearing correspond with access ports. For example, split the crank-shaft bearing on an engine connecting rod to permit bearing removal through the external access without necessity of removing the crankcase cover.

(43) Where accesses are located over dangerous mechanical components which can cause serious injury, design the access door so that it turns on an internal light automatically when opened. Also, provide a highly visible warning label on the access door.

(44) Provide for rapid inspection apertures on gear boxes, housings, and similar type of assemblies to permit inspection, adjustment, or when practical, repair or replacement of vital items

inside of these housings, without the necessity of major disassembly. These apertures may be plugs, windows, bailed hinged covers, or doors requiring no tools to open and close.

10-2.2 SERVICEABILITY CHECKLIST

(1) Are standard lubrication fittings used so that no special extensions or fittings are required?

(2) Are standard lubricants that are already in the Federal Supply System specified?

(3) Are adequate lubrication instructions provided that identify the frequency and type of lubricants required?

(4) Are filler areas for combustible materials located away from sources of heat or sparking and are spark resistant filler caps and nozzles used on such equipment?

(5) Are fluid replenishing points located so that there is little chance of spillage during servicing, especially on easily damaged equipment?

(6) Are filler openings located where they are readily accessible and do not require special funnels?

(7) Are air reservoir safety valves easily accessible, and located where pop-off action will not injure personnel?

(8) Are filler necks, air cocks, flexible lines or cables, pipe runs, fragile components and like items positioned so they are not likely to be used as convenient footholds or handholds, thereby sustaining damage?

(9) Where bleeds are required to remove entrapped air or gases from a pneumatic or hydraulic system, are they located in an easily operable and accessible position?

(10) Are drains provided on all fluid tanks and systems, fluid filled cases or pans, filter systems, float chambers, and other items designed or likely to contain fluid that would otherwise be difficult to remove?

(11) Are drain fittings of few types and sizes used, and are they standardized according to application throughout the system?

(12) Are valves or petcocks used in preference to drain plugs? Where drain plugs are used, do they require only common hand tools for operation, and does the design ensure adequate tool and work clearance for operation?

(13) Are drain cocks or valves clearly labeled to indicate open and closed positions, and the direction of movement required to open?

(14) Do drain cocks always close with clockwise motion and open with counterclockwise motion?

(15) When drain cocks are closed, is the handle designed to be in down position?

(16) Are drain points placed so that fluid will not drain on the technician or on sensitive equipment?

(17) Are drain points located at the lowest point when complete drainage is required or when separation of fluids is desired (as when water is drained out of fuel tanks)?

(18) Are drain points located to permit fluid drainage directly into a waste container without the use of adapters or piping?

(19) Are drain points placed where they are readily operable by the technician?

(20) Are instruction plates provided as necessary to ensure that system is properly prepared prior to draining?

(21) Are drain points located so that fuel or other combustible fluids cannot run down to, or collect in, starters, exhausts, or other hazardous areas?

(22) Are lubrication requirements reduced to as few types as possible?

(23) Are the same lubricants used in auxiliary or mounted equipment as in prime unit, where practical?

(24) Are easily distinguished or different types of fittings used for points or systems requiring different or incompatible lubricants?

(25) Are pressure fittings provided for the application of grease to bearings that are shielded from oil?

(26) Is ample reservoir space provided for grease to bearings in gear unit?

(27) Is provision made for a central lubrication or filler point, or a minimum number of points, to all areas requiring lubrication with a given system or component?

(28) Are service points provided, as necessary, to ensure adequate adjustment, alignment, lubrication, filling, changing, charging, and other services to all points requiring such servicing?

(29) Are fluid filler caps designed so that they:

- (a) Snap, then remain open or closed?
- (b) Provide large round opening for fluid filling?
- (c) Permit application of breather vents, dipsticks, and strainers?
- (d) Use hinges rather than dangerous chains for attaching the lid?
- (e) Are located external to enclosure, where possible, to eliminate necessity for access doors, plates, or hatches?

(30) Does design incorporate servicing features for cleaning, preserving, and refinishing equipment?

10-3 COMPONENT DESIGN FOR TEST ACCESSIBILITY

The following general guidelines, applicable to all general component types are recommended:

(1) All component test points should be brought out to a diagnostic connector to enable testing by an automatic tester.

(2) Where access is required to a component test point while the component is installed in the equipment, the test point should also be brought out to a readily accessible connector, either on the external surface of the vehicle or the top (or other exposed) surface of the component. The use of extender boards for electrical module test access should be minimized.

(3) Where isolation amplifiers, impedance transformers, or other means of signal conditioning are required for testing, the signal conditioner should be an integral part of the electrical module assembly if one exists. Signal test points should be isolated such that loading by required test equipment does not change the performance of the component, either when tested by itself or when installed in the equipment.

10-4 SPECIAL TOOL CONSIDERATIONS

The need for special tools such as jigs, fixtures, and templates to support maintenance actions is undesirable. The factors that follow should be considered in the event that a special maintenance tool requirement is being considered in the design:

(1) Cost Use of special tools involves more than the cost of their design and fabrication. MIL-STD-454 specifies that the special tools be mounted accessibly within equipment or in arrays located near the equipment installation. Conformance to this requirement adds to the cost of the design installation and of the securing fixture. A worst-case possibility of satisfying this requirement is the necessity of extensive equipment design to accommodate the tool.

(2) Maintenance and human factors engineering technicians do not like to use special tools and often find other means of accomplishing tasks that the special tool was designed to support. Individual refusal to use the special tool also could cause the task to be omitted or performed improperly, with resultant damage to the equipment.

Maintenance time sometimes is increased when a special tool is used. This is because the amount of time to perfrom the maintenance tasks must include time to secure the tool. At maintenance levels higher than the organizational level, special tools generally are kept in a tool crib with access and inventory control

procedures imposed. If a special tool is lost or misplaced, it becomes a critical item if a replacement cannot be obtained readily. The technician's unfamiliarity with the special tool also hampers its use. The technicians available often are involved in on-the-job training programs and have no prior knowledge of the special tool.

10-5 MOCKUPS

When designing large mechanical, hydraulic or pneumatic systems, a full-scale mockup may be used to function as a design tool in determining the optimum configuration to assist in packaging and in arrangement trade-off studies for selected components. Such a mockup offers a three-dimensional presentation to the engineers responsible for accessibility; the mockup may be used to establish effective arrangements or to resolve subsystem interface problems as they affect form, fit and function. The use of production materials in the construction of the full-scale mockup is not required. The full-scale structure can be lubricated from inexpensive materials such as plywood, plastic or foamcore and should represent accurately the size and location of structural members in areas which affect critical clearances. Major subsystem components, wiring, cables, tubing, piping and structural members should be mocked up (where relevant) to show the accessibility of inspection and maintenance.

CHAPTER 11
DESIGN TECHNIQUES FOR ATE COMPATIBILITY

SECTION I

IDENTIFICATION, STANDARDS, AND INTERCHANGEABILITY

11-1 SPECIFYING TEST POINT REQUIREMENTS

In the procurement of new equipments, requirements for test points may be specified in either a direct (explicit) or an indirect (implicit) manner. If the procurement agency is issuing a detailed design specification for the equipment, it may be possible to enumerate the test points and to specify the characteristics for each test point. If the equipment is specified on a functional or general performance basis, the selection of test points can only be derived in the course of the design of the equipment, and the purchase description can only impose the requirement that test points be provided to satisfy a number of test requirements. The procurement can impose a formal program for the development of test requirements and the design of test points, concurrent with the design of the prime hardware. It is important that the intent for the use of test points be well described so that subsequent hardware developments will be directed to meeting these goals. If the test points are intended for interfacing to a specific set of test equipment, the characteristics of the test point interface can be well defined. If the test points are intended to interface with general and undefined test equipment, it is desirable to establish standards for the test point interfaces, as this would enhance the selection of test equipment or the design of test equipment interface hardware.

11-1.1 PURPOSE OF THE TEST POINTS

Test points will be provided for any of the following reasons:

(1) Performance Monitoring of the Prime Equipment

Measurement made at the test points will permit the performance of the equipment to be evaluated. This may be required for verifying the operating condition of the equipment during normal operation (on-line) or during periodic checkups (off-line). The evaluation may be limited to overall functional performance or it may be desired to derive diagnostic information which either

predicts impending subsystem failure or identifies the existing failure.

(2) Enumeration of Functions to be Tested and the Characteristics of these Functions

Requirements for test points may be imposed in an implicit manner by the enumeration of test functions without specifically identifying the test points. In such cases, the functions to be evaluated must be specified, including the characteristics of the functions. For example, slewing rate, total range of travel, torque and steady state drift for a hydraulic servo loop could be specified as the measurable functions and the specification should include ranges and necessary measurement accuracies to be achieved. The equipment designer would in this case be responsible for establishing the necessary test points which will permit the functions to be evaluated. Note the distinction that test points permit the direct measurement of parameters (such as pressure, flow and position), but that the functional performance of the equipment may be derived from the systematic analysis of the measured parameters. Specifying test requirements at the functional level permits the equipment designer freedom to select alternate test methods and to exercise trade-off decisions which may be beneficial in meeting other goals in the design of the equipment.

(3) General Requirements for Test Accessibility

If the equipment specification is oriented to the functional performance of the prime hardware, rather than to explicit descriptions of the design, it will usually be necessary to specify test accessibility in general terms related to the intended purpose of testing. In this case, the equipment designer must participate in a program to develop concepts for testing, to lead to the eventual selection of test methods and specific test points. The decision process may be directed under the close guidance of the procuring agency or it may be delegated to the equipment designer. In any case, the decision process will require clear definitions of the mission intended for the test functions, including:

(a) Performance monitoring of the prime hardware
(b) Fault isolation to replaceable components
(c) Fault isolation for repair
(d) Alignment, adjustment or calibration

It must be recognized that providing adequate test points will, in general, conflict with other goals of the prime equipment designer, including consideration of cost, weight, safety and possible equipment degradation. The decisions necessary to establish test points cannot be made without trade-offs and the procuring agency must establish either a direct participation in these decisions or the designer must be provided with clear statements of priorities and overall requirements.

11-1.2 SPECIFYING THE USE OF ATE

In addition to specifying test point requirements in terms of the test mission, the procurement agency may wish to assure compatibility with ATE in the use of the test points. If a particular ATE exists at the time of procurement or, if interface standards exist for ATE interfaces, the equipment can be required to meet the test point interface requirements by specification. However, there are considerations which must be resolved in the application of ATE to the testing of an equipment, as discussed below:

(1) ATE Interface Standards

An ATE system may exist and be available for testing of the prime equipment at some level of maintenance. An ATE system may be under consideration for future development to support the testing of the prime equipment. Several ATE systems may be candidate test facilities, depending on the level of maintenance and the mission. In any of these cases, interface standards should be imposed (if extant) or should be derived so that prime equipment and ATE can achieve interface compatibility.

(2) Interface Adapter Hardware

The prime hardware designer may elect to solve the problem of test point interface to the ATE by the use of special interface adapters. This will permit the placement of interface transducers, signal conditioners, and similar devices which will be attached only at the time of test. The trade-off is reduction in the complexity, cost and weight of the prime hardware at the expense of added time required to attach the interface adapters at the time of testing. If adapter hardware is to be permitted in the interface with the ATE, interface specification are needed either at the ATE interface, the prime equipment interface, or both. If the prime equipment designer is also responsible for the interface hardware, only the ATE interface need be defined. If a third party provides the interface hardware, specifications at both interfaces are needed.

11-1.3 THE IMPACT OF ATE TESTING ON TEST POINT REQUIREMENTS

If ATE is intended for the testing of the prime equipment, the selection and design of test points can be affected. Normal design practices used by prime equipment designers may not be adequate, because of peculiar requirements for automatic testing. Some of these considerations are presented below:

(1) Provisions to Monitor Stimulus and Operating Conditions

The ATE may be able to control the operating conditions of the equipment during the test or, it may require manual intervention to establish the desired conditions. In either case, consistent and reliable test results cannot be achieved unless the

the ATE can verify that operating conditions at the time of measurement are within the bounds established for that test. This may require the addition of test points not normally considered, including the measurement of applied control signals, applied power sources and applied loads. Where possible, the ATE should be able to control input signals and output loads directly, and to monitor the conditions of the inputs and loads. If direct control by the ATE is not possible, the ability to monitor these functions is a highly desired alternate.

(2) Measurement Accuracies

The prime equipment designer may specify that measurements taken at the test points provided should be obtained within stated accuracies. If components imbedded in the prime hardware contribute to the accuracy of the measurements, the designer must consider the means of calibration, as well as the effects of external loads and the bandwidth of external measurements. In addition, the designer must consider the ability to couple the measurement transducer to the physical parameter at the desired point of measurement, such as the placement of a temperature transducer near the desired bearing, or the placement of a pressure tap within a dynamic fluid path.

(3) Test Method Enhancement with ATE

Because of the processing capabilities of an ATE, it may be possible to derive test and measurement techniques not normally present in a conventional test system. Software processing to filter noisy measurements is a simple example and the possibilities extend to techniques for signal (waveform) analysis, correlation techniques and mathematical modelling for diagnostic predictions.

11-2 INTERFACE COMPATIBILITY WITH AUTOMATIC TEST EQUIPMENT

It is likely that future designs will be required to provide standardized interfaces for the connection of external, automatic test equipment. It will be necessary to provide standards for the ATE and for the prime equipment in order to make this feasible. A few considerations towards this end are presented in the following paragraphs.

11-2.1 INTERFACING WITH HYDRAULIC, PNEUMATIC AND MECHANICAL SYSTEMS

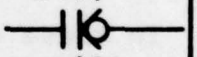
The transfer of control signals to the component being tested and measurement signals from the component requires interface connections between the ATE and the component. The reliability and ease of use of these connections are described below:

11-2.1.1 Fluid Interface Fittings

In the course of performing automatic testing on fluid systems (either pneumatic or hydraulic), it is usually necessary to tap into one or more fluid lines. The only exception to this would occur in a high-cost, elaborate system under test (such as a gas turbine) for which all necessary fluid-to-electrical signal transducers are permanently installed as a part of the system (BITE). In all other cases, the equipment designer must provide ports for the connection of pressure measurement transducers in a convenient form.

Clearly, all the usual pipe or tubing connections are at his disposal, but if he chooses the most basic of these requiring a wrench for the connection/disconnection procedure, he is doing a disservice to the test facility. Except in most unusual circumstances in which an especially hazardous fluid is involved, the choice should be for one of the many varieties of quick-disconnect couplings that are available today. These fall into the classes listed in Table 11-1.

TABLE 11-1. FLUID QUICK-DISCONNECT DEVICES

	ANSI Symbols*	
	Mated	Unmated
A - Connection without shutoff		
B - Connection with one-sided shutoff		
C - Connection with two-sided shutoff		

*Note: one may not discern from the standard symbols, which is the plug and which the socket.

Variations on the type above are also found as:

- C1 - Connection/disconnection with little or zero liquid leakage.
- B1 - Disconnection with slide valve to de-pressurize pneumatic line before disconnection.
- A1 - Low-cost disconnects for low pressure (below about 100psi) for either pneumatic or liquid service. (These devices can usually be disconnected under rated pressure hence care must be used that a liquid spray does not do eye damage during disconnection)

The ANSI standard symbols are the same for this latter group as for the corresponding basic group. An example of Type C and

A1 are found in Figures 11-1 and 11-2 respectively.

11-2.1.1.1 Sizing of Fluid Disconnect Devices - For most applications involving automated testing, the pressure rating of the coupling device and the compatability of the seal material with the type of fluid are the most significant parameters by which the device is to be selected. Fluid flow capacity is very seldom found to be pertinent since all pressure transducers are dead-headed and so, in the steady state at least, no flow is present in these interface connections. Accordingly, only the smallest sizes in the available hardware need be considered for the service.

Even extremes of fluid temperature in the operating system are seldom encountered by these connectors since, again, the dead-headed fluid column will not transfer its maximum temperature to the coupling. (However, a conservative design might assume this highest temperature for selection of the coupling).

11-2.1.1.2 Couplings for Applications of Significant Fluid Flow- In a limited number of cases, significant flow may be required in the coupling, as in the following cases:

(1) Sampling flow from a hydraulic system or engine oil to measure the particulate contamination.

(2) Bypassing of major flow through a test turbine flowmeter to measure flow rate in a hydraulic system.

In these cases, it should be understood that some additional pressure drop will be unavoidable in the process of diverting flow and it may be computed as follows:

(1) For the turbine flowmeter, typical pressure drop across the meter at its maximum flow rating is about 10 psi.

(2) The additional pressure drop in the quick-connect couplings is estimated for liquids by:

$$\Delta p = \left(\frac{q}{c_v}\right)^2 \rho$$

where

Δp = expected pressure drop in psid

q = flow rate in gpm

c_v = flow capacity rating of the mated coupling

ρ = specific gravity of the liquid

Two-Way Shut-Off Couplings positively seal both ends of line when Coupling is disconnected.

Spring actuated valves in both Socket and Plug provide immediate and positive seal against escape of gas or liquid.

When connected, complete seal is effected by compression of O-ring in Socket against outside surface of Plug.

Operation:

To connect, merely pull back sleeve, push Plug into Socket.

To disconnect, pull back sleeve, unlocking Coupling and sealing both ends of line.

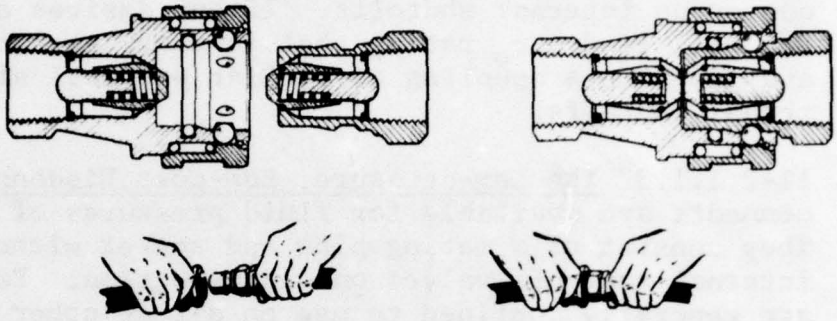


Figure 11-1. Typical Fluid Quick-Disconnect, Type C

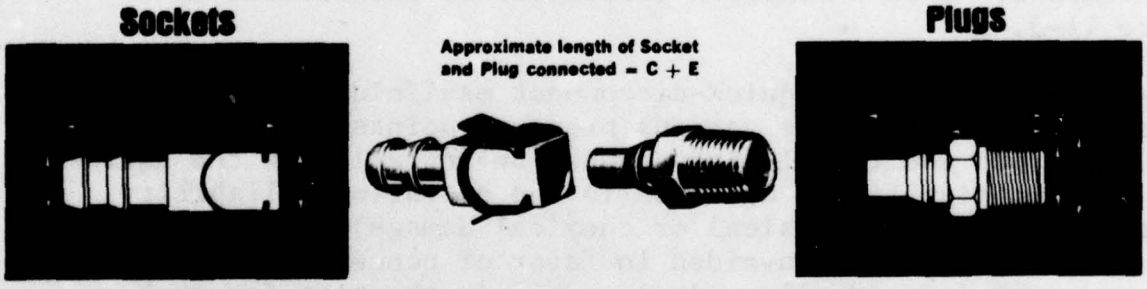


Figure 11-2. Typical Fluid Quick-Disconnect, Type A1

The c_v rating is given for the combined two halves of the coupling as mated. It will be found to be very different for a similar physical size of coupling depending on whether it contains two, one or no internal shutoffs. If one desires a dual shutoff, one will find a c_v rating that is much lower than that which is available in a coupling of similar physical size having no internal shutoffs.

11-2.1.1.3 The Low-pressure, Low-cost Disconnect - These disconnects are available for fluid pressures of roughly 100 psi. They consist of a mating plug and socket without the option of internal shut-off valves on disconnection. For this reason they are generally confined to use on air or other gases where spillage on disconnection is of no consequence.

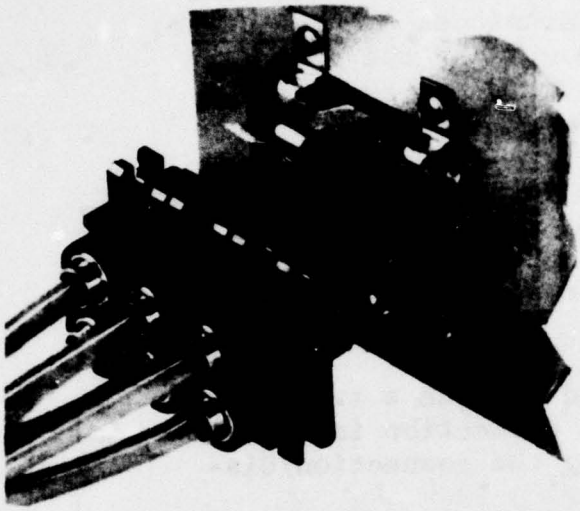
Additionally, after disconnection, a plug must be inserted to block the interface so that normal operation of the system is possible and it is a hazard of these devices that it is possible to release this plug with pressure behind it and create a projectile.

Notwithstanding the above limitations of operation, there is an additional significant advantage of using this type of device.

They may be obtained in a manifold disconnect configuration so that connection to several taps may be made simultaneously. This makes a very convenient interface for multiple low pressure measurements. Such a manifold disconnect is illustrated in Figure 11-3.

The use of a pressure quick-disconnect manifold implies additional lines to bring the various pressure points to the manifold. If such additional lines cannot be installed in the equipment without significant decrease in the operating reliability (because of possible physical or chemical damage) then the manifold approach should be avoided in favor of connections to each pressure port individually. An increase in the time for such connection preparatory to running the test must be assumed.

11-2.1.1.4 Protection of Fluid Couplings Against Dust, Dirt and Moisture - If the equipment designer has chosen quick disconnects of Type A in which no internal valve is provided, then he has, of necessity, provided a plug for closing this port under normal operation so that not only will the working fluid be contained but the possibility of dirt contamination of the coupling will be avoided.



MODULAR
PLUG IN CONNECTORS

FOR TUBES 1/8", 5/32" AND 3/16" O.D.

LIKE AN ELECTRICAL CONNECTOR,
THIS PNEUMATIC MODULAR
CONNECTOR ENABLES CONNECTION OF A GROUP OF
PNEUMATIC TUBES
BY A SIMPLE SNAP TOGETHER ACTION.

Figure 11-3. Typical Manifold Gas Quick-Disconnect Connector

On the other hand, the selection of a type C coupling implies no need for a pressure plug for normal operation of the equipment. Nevertheless, protection from contamination of the sensitive parts of the coupling is still required, (or a pressurized cleaning process to expel such contamination before mating the coupling) and this, in turn, necessitates the use of a local enclosure or reliable dust cover. It is the equipment designer's responsibility to provide such protection for normal equipment operating conditions.

11-2.1.2 Temperature Measurement Interface

As in the case of pressure measurement, if the temperature transducer(s) are permanently mounted to the equipment, then the interface is electrical and is relatively straightforward (provided the transducer is not a thermocouple requiring specific wire materials and connections).

However, where the temperature transducer is part of the ATE,

and measurement of a fluid is required, it is considerably more difficult to provide a simple, inexpensive interface with the component to be tested. At least two techniques are available:

(1) Provision of a temperature probe well by the equipment designer. (This permits ready installation of a temperature probe but substantially slows the response of the probe to transient temperature effects).

(2) Use of an elastomeric valve that permits direct insertion of a narrow probe into the fluid stream. Such a valve is illustrated in Figure 11-4. The probe will normally be an RTD (resistance-temperature-device) type made of a nickel or platinum material.

Note that to exclude dirt and dust and provide a tight fluid seal, a plug is used except when a test connection is required. A few drops of liquid may be lost during the connection/disconnection process.

Where the measurement of the surface temperature of a metal is desired, the interface is much simpler and involves such mechanical fastening devices for an RTD or semi-conductor transducer as:

(1) Quick-connect clamps (as a V-band clamp)
(2) Bolt or screw fastener
(3) Toggle lever clamp

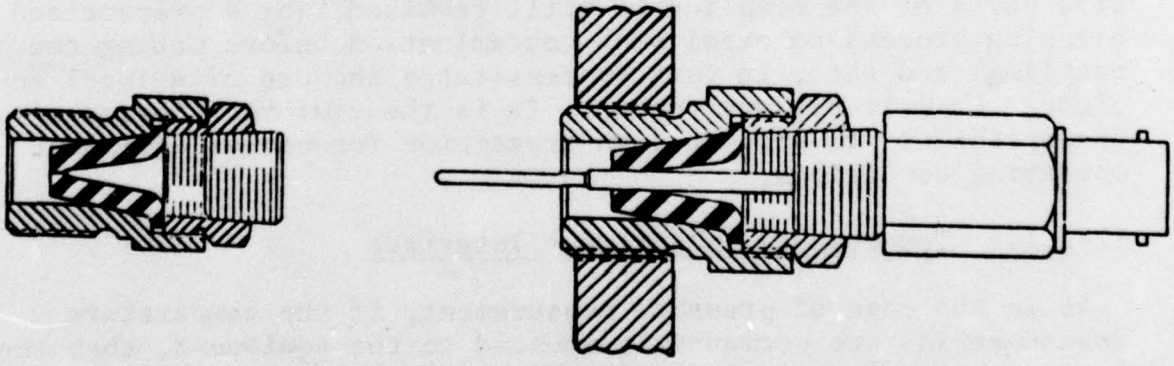


Figure 11-4. A Convenient Temperature Probe Interface for Fluids

11-2.1.3 Electrical Interface Connectors for Automated Testing

Experience has shown that quick disconnect connectors are superior for ruggedized military applications involving automated testing. Three military specifications are recommended for this use in the listed preferred order:

1. MIL-C-26482
2. MIL-C-5015
3. MIL-C-81511

It is recommended that MIL-C-26482 be designated as the standard electrical connector specification for use in fielded automatic test applications. This connector features quick disconnect, environment resisting, miniature, circular case with hermetic receptacles. For standardization purposes it is important that the selected connectors be intermateable even between the connectors of the three MIL specifications preferred. MIL-C-81511 connectors are recommended only where extreme environments are encountered or where scoop-proof connection is required.

For some automotive applications, electrical interface techniques are well served by the solid shell version (MS31XXX-XX-XX) of the multi-pin connector series of MIL-C-5015D. MIL-C-50150 connectors can be used where large conductor, large connector application is the only answer. The multi-pin connector mentioned below is one of this class.

11-2.1.3.1 Preferred Bayonet-Style Connection - Experience has shown that one may reduce the time for making connections by employing the bayonet principal instead of the usual fine thread on the MS connector without jeopardizing the reliability of the connection. A connector series of this type is available and has been found to be ideal for the main ATE electrical interface for at least one system presently under development. This is the CA3100 connector class with a 2010 contact arrangement (54 pins, size #16 conductors). Standardization to this connector type is highly desirable for heavy current vehicle applications. It utilizes a special mechanical ramp to pull the connector halves together during mating.

11-2.1.3.2 Special Electrical Measurements - There are occasional special requirements for which the usual techniques are unsuitable. Where high-voltage (ignition) system measurements are to be made, the following techniques are recommended for consideration when making current and voltage measurements on the secondary side of the ignition coil:

(1) Current Measurement Requirement

Recommended: A toroid surrounding a high voltage lead to provide a signal proportional to the rate of change or current.
Purpose: Providing a synchronizing signal to indicate the firing of Number 1 cylinder (or any others that are useful).

(2) Voltage Measurement Requirement

Recommended: A high voltage capacitor in a capacitor divider is useful to provide a signal proportional to the igniting voltage,

Purpose: To indicate the value of high voltage for any given plug lead.

These techniques do not necessarily create a need for special connectors (interfaces to the ATE). Clearly, the low voltage signals generated in the above recommendations can be made available on the standard 54-pin connector already discussed.

11-2.1.4 Electrical Interference

A primary concern, in the design of electrical interface, is the effect of electrical interference between signals. Noise sources present in vehicle systems such as pulsating high voltages (ignition systems) and heavy current demands can generate serious problems in the vehicle/ATE interface. If not properly addressed, such problems can result in erroneous test results, and even in potentially damaging signal levels.

In most instances, standard design techniques for shielding and grounding will provide acceptable results. The designer should be aware, however, that unique situations can arise which will require unique methods. Elimination or reduction of interference effects must be considered from two aspects. First and most obvious is the guarding of signal lines to prevent pick up. Of equal importance are the considerations given to confining interference at the source.

While it is clear that no single technique will guarantee complete results, the designer should begin with certain basic conventions. Shielding of signal lines is effective, but only when proper concepts are derived and adhered to. Grounding philosophy for shields becomes a important consideration. The use of twisted wire cables tends to equalize pickup (common mode) in signal lines. If source impedances are maintained at low and balanced levels, and suitable differential measurement techniques are employed, the effect of interference can be cancelled. Due to the close coupling of twisted pair, shunt capacitance can be a problem, especially in long runs. Where such capacitance

is critical, as in the case of higher frequency measurements, the designer may be forced to consider other types of cable. Where very low level signals are to be processed, and long cable runs are involved, it is sometimes advisable to consider preconditioning (amplification) at the signal source.

Design and location of signal harnesses should be of concern to the designer. If the noise source can be kept isolated from signal lines, the effort expended on reducing the effect of pickup is minimized. Signals which are likely to cause problems of interference are frequently included in the ATE interface, and should, therefore, be properly routed. Pin assignments at the interface connector can be made in a manner which maintains separation between critical and noisy signals.

11-2.1.5 Isolation and Protection

Provision should be made in interface design to preclude performance degradation or damage either to the ATE or to the component being tested should a malfunction in either occur. Such protection can often be provided by simply placing a resistance in series between the interface and the monitor point. Care should be taken in the selection of such devices to insure the measured signal is not degraded as a result. No concrete ground rules exist for sizing. Too low in value, and protection may be inadequate. Too large and significant signal attenuation and bandwidth limitations result. Unrealistic demands should not be imposed on ATE input characteristics. It is important that when differential signals are being treated, the balance in source impedance be maintained. Similar precautions are advised when connecting between vehicle systems and on board BITE. Such connections should not impair or degrade normal vehicle performance.

11-2.1.6 Typical Measurements

(1) Many of the measurements performed in vehicle test will require some form of transducer. Pressures, temperatures, torques, etc. are converted to an electrical signal proportional to the parameter. Such signals are generally considered low level and may require special handling. Cabling shielding and preconditioning, previously discussed, are particularly critical when dealing with these devices. Stimuli required for transducer excitation can be either a part of the ATE or may be carried on board the vehicle. In either case attention should be given to

standardization of levels, frequencies, etc. Not to be overlooked is the effect of line loss on stimulus inputs especially where low impedance devices are used.

Provisions for self test and calibration should be considered by the designer. In resistance bridge devices a selectable predetermined bridge unbalance can be implemented. The resultant signal can be used as either a self test indicator or a point for calibration of the transducer. Figure 11-5 illustrates a typical transducer configuration. Note the use of multi conductor shielded cable and the shield termination (ground) at the ATE.

(2) High Voltage (Ignition System)

The processing of ignition system signals demands careful attention to signal conditioning and routing. Pre-conditioning generally involves scaling signals down to manageable levels immediately at the signal source. Techniques which have proved successful include ferrite coil pick offs and high voltage capacitive dividers. As waveform analysis is often employed for interpretation of ignition data the designer should be aware of bandwidth limitations for the conditioning scheme selected. Similar attention must be given to the signal cabling which, if not properly selected, may cause severe signal degradation. In addition, the designer should be aware of potential vehicle system degradation resulting from the signal conditioning, particularly when such hardware is permanently installed. Figure 11-6 illustrates a high voltage pickoff used as a reference signal for ignition timing. Signal conditioning may include active circuitry or may be a simple impedance matching network.

(3) Electrical System

In the typical ATE/vehicle hook-up, several points within the vehicle primary electrical system will be monitored. Here again the measurement ground philosophy should be carefully considered by the designer. Recognizing that the ground potential, relative to the prime power source, will vary widely throughout the system, satisfactory measurement results may demand direct point of load sensing using differential techniques. As in the case of low voltage measurements, the designer should insure that proper cabling and shielding methods are employed to insure signal integrity. Where isolation techniques are employed, it is important that impedances be balanced to offset common mode effects. Figure 11-7 illustrates a typical connection for electrical system measurements. Isolation resistors are included to preclude equipment damage in the event of malfunction. In this application, the cable shield is expected to provide better performance by connection at the vehicle or sending end. Note too, that the isolation resistors are depicted as being shielded

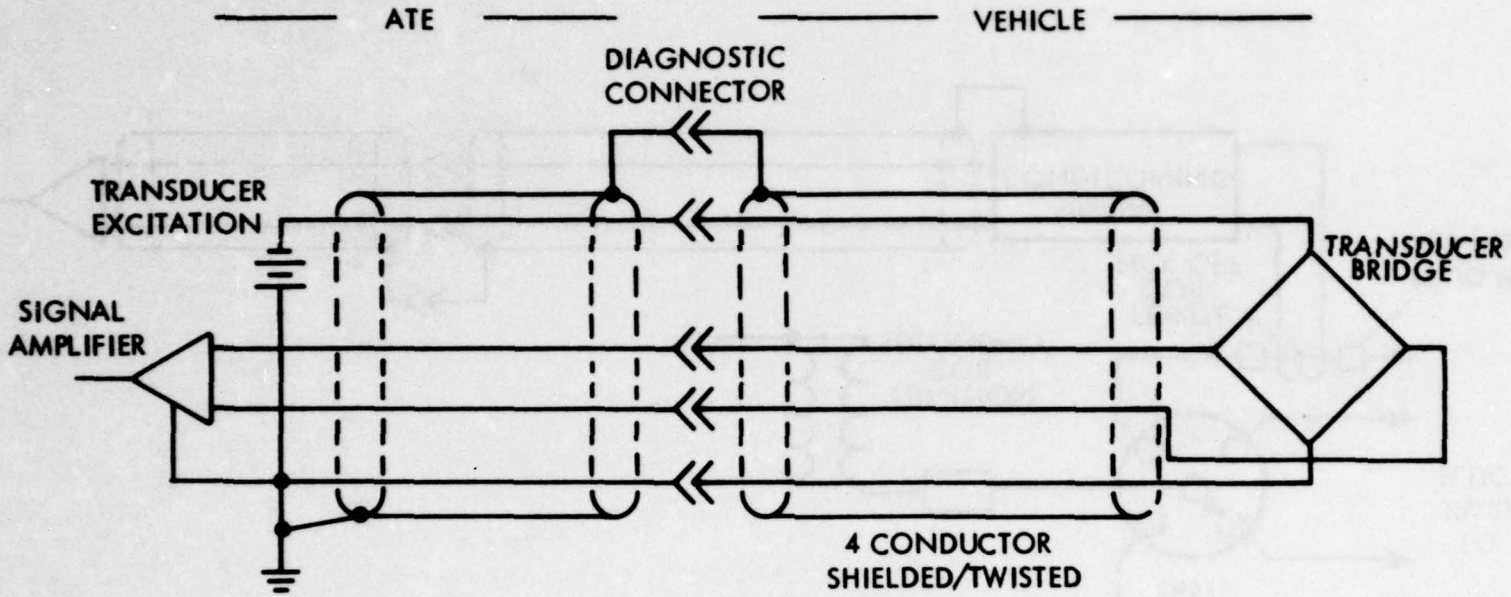


Figure 11-5. Typical Transducer Hookup

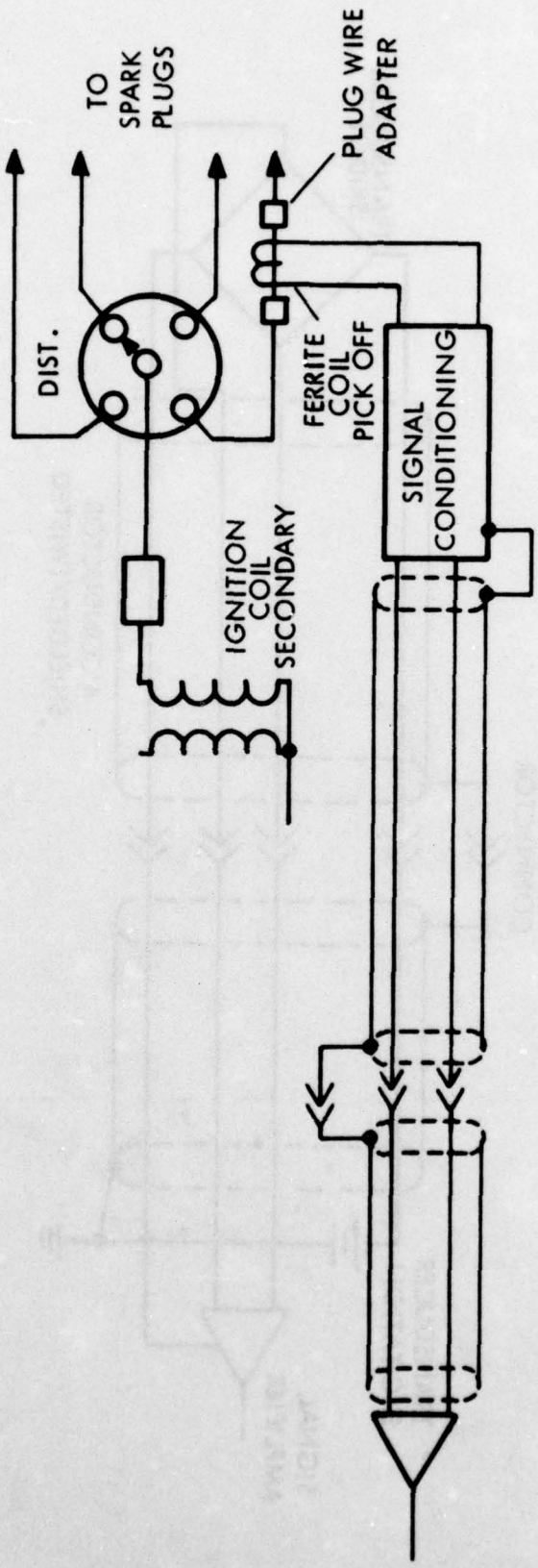


Figure 11-6. Typical Inductive Pickoff, Ignition Signal Hookup

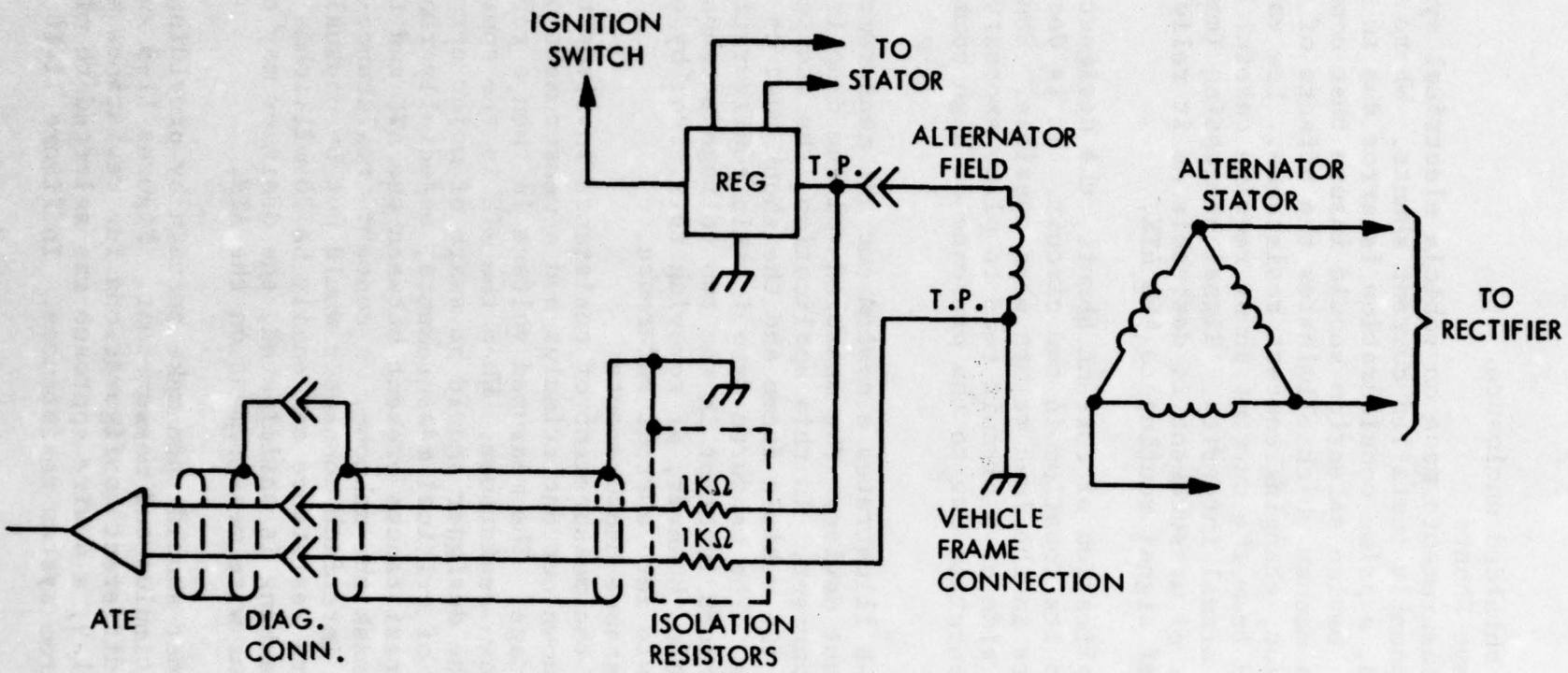


Figure 11-7. Typical Electrical System Measurement Hookup

or within a shielded enclosure.

(4) Current Shunts

Current measurements made on vehicle electrical systems may employ permanently installed current shunts. Where such devices are employed, a prime consideration is error due to contact resistance. Device selection should insure that connection can be made in a manner which eliminates the effects of initial and, more important, changing contact resistance. Low voltage signals derived from the current shunt require careful processing to preserve signal integrity. Signal processing (amplification) at the point of measurement is desirable as it relieves much of the burden of signal routing to the ATE.

In the application of current shunts, the designer should give attention to its location in the circuit. It is desirable to locate shunts in the load return when possible. Shunts located in the high side of a circuit tend to place excessive demands on ATE instrumentation due to the presence of high common mode voltages.

Figure 11-8 illustrates a system current measurement using an in-place shunt device. The measured voltage drop is a measure of starter current. In this application, the starter return side is via the vehicle frame and the shunt must be placed in the hot side. The measured drop in this configuration may be masked by errors inherent in the two voltage attenuators. The ATE is capable, however, of removing this error by establishing an appropriate zero current reference.

(5) Resistance Measurements

Typically the measurement of resistance involves the application of a known current stimulus and a measurement of the resultant voltage. The measured voltage is then a representation of the unknown resistance. When the ATE is the source of current stimulus, the designer should be aware of major error sources. In the case of critical measurements, especially those of low value, the resistances present between the ATE and the unknown can easily mask the unknown. A contact resistance of 50 milliohms at the interface connector would not be unusual, and the per foot wire resistance can easily be 20 milliohms or greater. When such masking is anticipated, the designer may consider imposing a four wire measurement on the ATE.

The designer should then make certain by providing separate paths for stimulus and measurement. Figures 11-9 and 11-10 depict two different configurations for resistance measurement. In Figure 11-9, a 4 wire approach was selected to minimize errors resulting from system resistances. In Figure 11-10, the expected

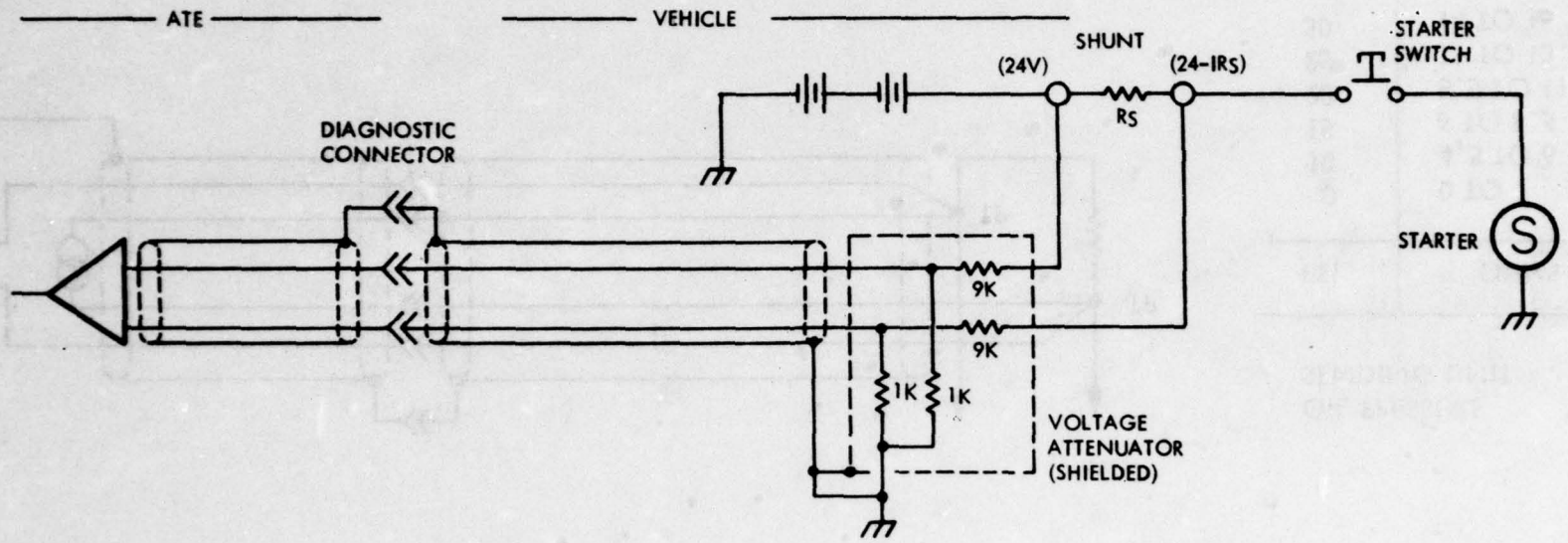
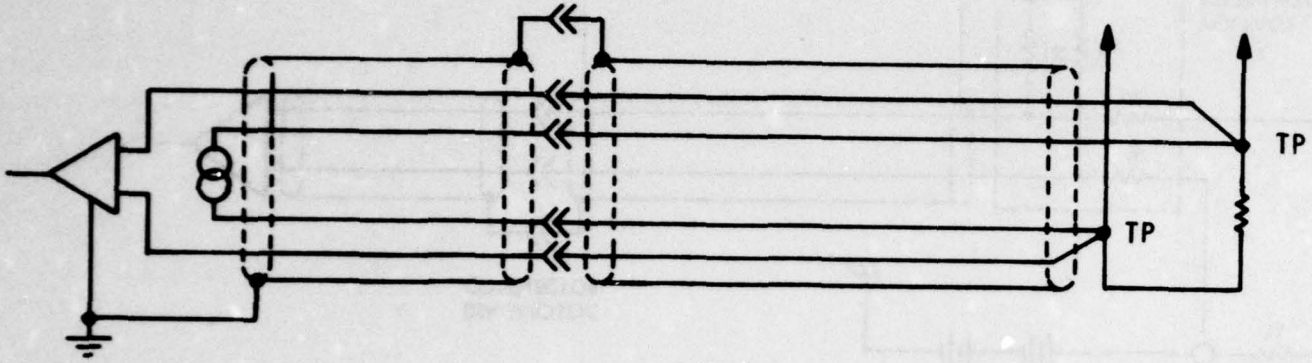


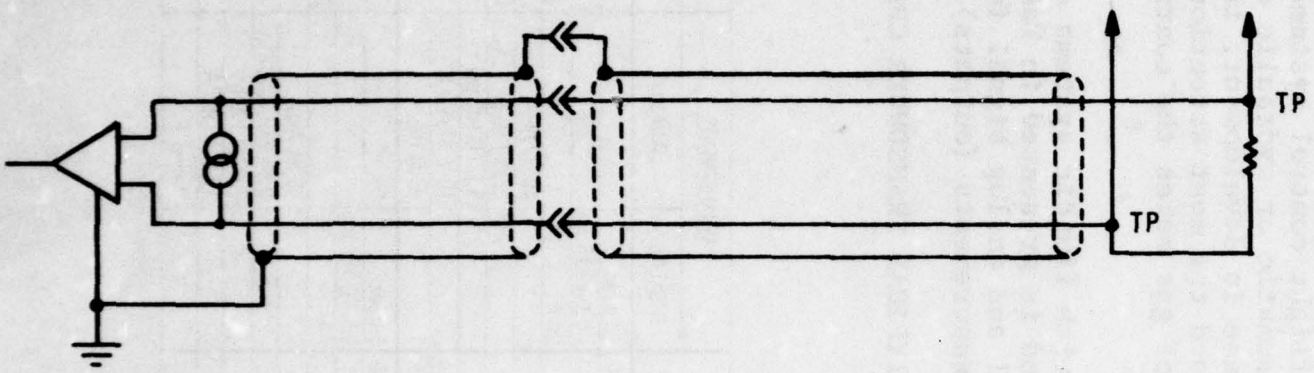
Figure 11-8. Typical Current Measurement Hookup Using Shunt



OIL PRESSURE
SENDING UNIT

PSI	OHMS
0	0 TO 1
10	4.5 TO 6
15	6 TO 8.5
20	8.5 TO 11
25	11 TO 13.5
30	14 TO 16

Figure 11-9. Typical Four-Wire Low Resistance Measurement Hookup



TEMPERATURE SENDING UNIT

DEG (F)	OHMS
160	1200
180	917
240	450

Figure 11-10. Typical Two-Wire Resistance Measurement Hookup

unknown is of sufficient magnitude that system resistances are not significant. Here a simple two wire approach is selected.

11-2.2 INTERFACING TO FLUIDIC CONTROL SYSTEMS (PNEUMATIC AND HYDRAULIC)

Fluidic control components have had substantial development over the last decade, but few applications. Among these few, however, are applications as the stability-augmentation-system (SAS) in helicopter flight control systems. Although, theoretically, either pneumatic or hydraulic operation is possible, because of greater ease in development, the hydraulic fluidic controller has received the most attention (As in servo systems, the compressibility of gas makes the control problem more difficult).

The ATE interface with fluidic systems of both types has been estimated (Ref. 1) and is presented in Table 11-2. The table includes both digital and analog signal functions for both commands (inputs) and measurements (outputs).

TABLE 11-2. TYPICAL TRANSDUCER CHARACTERISTICS

	PARAMETER	MEASUREMENTS		COMMANDS	
		DIGITAL	ANALOG	DIGITAL	ANALOG
PNEUMATIC	SWITCHING SPEED	10 msec		1.6 msec	
	SWITCH LEVEL	−0.5,+0.15 psi			
	AMPERAGE	20 A		0.25 W @ 12 V DC	
	SCALE FACTOR		40 mV/psi		0.1 psi/V
	LINEARITY		0.5% FULL SCALE		2% FULL SCALE
	RANGE POWER		0.5 TO 100 psi		0.5 TO 1.0 psi
	POWER		10 V @ 35 mA		4 V, 20 mA
	RESPONSE		>100 Hz		15 Hz
HYDRAULIC	SWITCHING SPEED	5 msec		1.6 msec	
	SWITCH LEVEL	0.5 TO 100 psi			
	AMPERAGE	7 A		0.25 W @ 12 V DC	
	SCALE FACTOR		40 mV/psi		0.0015 $in.^3$/sec/mA
	LINEARITY		0.5% FULL SCALE		<7% FULL SCALE
	RANGE		0.5 TO 100 psi		±10 psi (diff)
	POWER		10 V @ 35 mA		±10 mA
	RESPONSE		>100 Hz		125 Hz

11-2.2.1 Hydraulic Test Points/Test Ports

Hydraulic testing has not been standardized to the point of specifying the fittings and hoses to be used for connection with test equipment. It is recommended that this be accomplished in military specification form as soon as is practicable. Some military commands have used a form of specification in their purchase requirements. An example of a test point purchase requirement for construction equipment follows:

Test Points. Steel fittings shall be provided in the hydraulic system for attachment of a hydraulic system tester. One test point fitting shall be in the return line upstream from and adjacent to the filter and one fitting shall be connected to the outlet of each pump. For line sizes 1 inch and larger, the test point fitting shall have a branch terminating in a 4-bolt, split-flange port face conforming to MS39314. For line sizes smaller than 1-inch, the test point fitting shall have a branch terminating in a SAE J514b, 37-degree flare male, of the same nominal size as the line. The location of the test point fittings shall be such:

(a) that attachment of a tester hose can be accomplished without the removal of any component other than sealing caps and access panels or plates,

(b) that the tester hose can be attached with standard open-end wrenches,

(c) and that two 10-foot lengths of hose, one attached to the return line test point and the other alternately attached to each pump outlet test point, extend beyond the external surface of the vehicle to a flat horizontal surface on which the connected tester may be placed.

Sealing and sealing caps. The 1-inch, 4-bolt, split-flange fitting shall be sealed with a cap with "O" -ring. The 37-degree flare fittings shall be sealed with a cap conforming to SAE J514a of applicable size. When a test point sealing cap is removed, the maximum system fluid loss shall not exceed 8 fluid ounces. If check valves are used to limit test point fluid loss, the maximum pressure drop across the check valve shall not exceed 5 psi.

11-2.3 LOADING AND GROUNDING CONSIDERATIONS

The connection of an external test set for measurements of parameters on a prime equipment cannot ignore fundamental grounding and shielding considerations. The exact nature of the connection problem will depend on the type of prime equipment and

the environment in which it is tested, but a few concepts should be considered.

If the prime equipment supplies the source of the electrical signal, via a diagnostic connector or other interface means, the problem of signal level, reference ground, common mode noise, and shielding must be considered. For small signal levels (less than 0.5 volts) signal leads must be twisted to reduce low frequency differential mode pickup and shielded to reduce radiated coupled interference. No single statement can be made regarding the best concept for grounding of shields, but a grounding plan for both the test system and the prime hardware should be established for the ground system to be effective. Effects of common mode noise (signals induced into both the high and low wires of the transducer leads) can be minimized if the transducers have a balanced output and if the test system input presents a balanced load. If either line in the transducer and or the measurement system end represents a different impedance to ground, common mode currents cannot be cancelled and suppression of noise will then be subject to the integrity of the grounds.

When interfacing with electrically noisy prime system, care must be taken to avoid coupling the noise into the measurement system. With spark ignition engines. the high energy in the spark can interfere with analog measurements if this type of noise is not contained. Coupling the spark waveform through a transformer (ferrite coil) is one good means of minimizing the high frequency currents which might otherwise get into analog return lines and create measurement errors.

11-2.4 ATE TEST POINT GUIDELINES

The following list is not intended as a complete checklist to cover all aspects of planning for test points on a new equipment design, but it does include a number of the more important concepts discussed in this design guideline.

(1) Be sure to include test points which may be required for all of the following categories:
   (a) Fault detection tests (Determine that a fault exists)
   (b) Fault isolation tests (Determine which level of subassembly repair/replacement is needed)
   (c) Alignment, adjustment, or calibration (provide access as needed to make adjustments to a component while it is situated within the prime equipment)

(2) Check on existing standards for test point interfaces related to either:

(a) The types of prime equipments being designed, or
(b) The types of test equipments or ATE which will be used in servicing the prime equipment

(3) Check for interface standards, or impose interface standards, for the following types of considerations:
(a) Type of interface connectors (both electrical and mechanical)
(b) Pin assignments to test functions on electrical test connectors
(c) Standards for signal interface to include
1. Accuracy or resolution
2. Bandwidth or range of frequency
3. Range of voltages, pressures, etc
4. Impedance/load
5. Grounding/shielding
(d) Standard test connector locations

(4) Be sure to consider connections (either electrical, hydraulic, pneumatic, or mechanical) for the connection of:
(a) External stimulus
(b) External loads
(c) Control of system mode

(5) In hydraulic systems be sure to provide connections for:
(a) Collection of fluid sample for contamination monitoring
(b) Location of pressure taps to provide monitoring of dynamic flow situation
(c) Location of temperature sensing points to permit monitoring of dynamic temperature gradient situation

(6) For sensors mounted within the prime system be sure to consider:
(a) Means for self test and calibration of the sensors
(b) Compatibility requirements with external test system

11-3 STANDARDIZED ATE INTERFACE

Ideally, prime equipments would be built with a standardized diagnostic test harness to provide interface to an automatic (or other) test set. Such standardization is possible if the ATE system is well specified, if the interface requirements are well specified and if the prime equipment is procured with a requirement for this type of interface.

At the time of publishing this design guide, some initial efforts have been undertaken by the US Army (TACOM) to specify diagnostic connectors for a number of vehicles, including the M113 A1 armored personnel carrier, M35A2 2½ ton 6 x 6 truck, M48A3

tank and M151A2 ¼-ton truck. The designer of any new equipment should check the status of such standards at the time of the design, for the possibility of sharing in standardized test interfaces. Standardization can be achieved in any of the following categories:

(1) Selection of electrical interface connector type, to include the number of pins, pin arrangement and plug/connector part number.

(2) Standards for assignment of types of signals to pin numbers.

(3) Standards for hydraulic and mechanical connectors.

(4) Standards for the levels of signals, types of analog and digital signals, digital signal formats, timing signals, signal accuracies, ranges, resolution, impedances, loading capabilities, grounding and shielding.

11-4 STIMULUS TEST ACCESSIBILITY

The need for special stimuli in the course of automated testing is almost always absent, provided the equipment being tested is an autonomous system and not simply a component of a system. In other words, the tests of an internal combustion engine or a hydraulic system generally can proceed without any need for stimuli other than those normally provided within the equipment under test. But, if the carburetor is removed for individual tests, or if the hydraulic pump or control valve is removed from a hydraulic system, then the test facility must provide the often elaborate interface needed to simulate the operating conditions and appropriate stimuli become necessary for test purposes.

The exception to this general state of affairs occurs when unsteady tests with critical timing in the measurement of test parameters is involved. An example in engine testing is the transient measurement of horsepower by means of a full throttle acceleration test. It is very desirable that the acceleration profile be initiated by the ATE so that no unnecessary data storage will preceed or follow the significant event. One may solve this problem in one of two ways:

(1) Provide an electro-mechanical actuator that will attach to and operate the throttle on signal from the ATE.

(2) Inhibit the data taking by the ATE until a remote sensor indicates that the throttle has been manually depressed.

It is seen that, by using the second approach, the need for a stimulus has disappeared and been replaced by the need for a discrete sensor, a device that is quite a bit simpler than the actuator-stimulus device.

In hydraulic systems, for example on the hydraulic subsystem of many helicopters, it is conventional to provide access ports so that an external hydraulic pressure source can be connected to the subsystem for the purpose of testing, thus permitting its test without running the main helicopter engine. This can be of special importance for the following reasons:

(1) the hydraulics can be checked at times when the main engine is not operable, or it is not convenient to run it.

(2) the hydraulic system can be checked over controlled range of input pressures, a situation not realizable running from the actual helicopter engine.

In general, however, the application of external stimulus is not provided as the recommended mode of operation during the testing of mechanical systems, as the prime vehicle power will be the power source.

11-5 CONSIDERATIONS FOR BUILT-IN TRANSDUCERS AND SIGNAL CONDITIONERS

There are two principle reasons for considering the use of built in transducers and signal conditioners to be a part of an operating system. First, the parameter being measured may be desired for monitoring during normal operation of the system and may be wired to displays. The decision to implant such devices will be derived primarily from the operational requirements of the system, but the signals, if properly isolated and made available for test equipment interface, can be very useful in fulfilling test requirements. The second reason for implanting such devices is to serve the test function by permitting access to parameters more quickly or with more convenience. By embedding the transducers and their signal conditioners at the point of measurement and bringing electrical harnesses to convenient electrical connectors, the diagnostic connector can be made the interface to the test system and considerable time can be saved in attaching the test system. The advantages of built in transducers can be appreciable and in some missions, it may be the only viable solution to a satisfactory maintenance program. However, the use of built in devices presents the prime equipment designer with a number of problems which he must carefully address.

11-5.1 EFFECT OF OPERATING ENVIRONMENT

The operating environment of some systems may include extremes of temperature, vibration and physical contamination which may severely affect the life of the transducers and their signal

conditioners. Devices which will perform the measurement functions reliably in the environment of the test location may not be suitable for imbedding on the test system. Transducers and devices cannot be considered for such use unless they are qualified for all of the extremes which may be encountered.

11-5.2 CALIBRATION OF BUILT-IN TRANSDUCERS AND FAILURE DETECTION

Another problem which is difficult to solve involves the calibration of built in transducers and the detection of their failures. Since the transducer has been imbedded in the test system to avoid the bother of attaching external transducers, and to avoid having to provide access ports for that function, the transducers will usually have to be connected to the test system with an unknown state of calibration. If the transducer has no output and other measured parameters in the system indicate that there should be an output, the failure condition of the transducer can be detected. However, partial degradation of the signal could not be discerned from the degradation of the parameter being measured. Transducers imbedded in test systems should have a greater reliability and greater stable lifetime than the systems which they are monitoring. If this can be achieved, equipments will be diagnosed as no-go and subsequently torn down for repair only rarely because of bad measurement devices.

11-5.3 CONTROL OF BUILT-IN TRANSDUCER LIFE SPAN BY MAINTENANCE POLICIES

If the reliable and stable lifetime of the transducer and its conditioners can be predicted, maintenance policies can be established to replace these devices within certain operating intervals. In prime equipments where periodic overhaul is scheduled, the replacement of such transducers can be scheduled and readily controlled. If overhaul of the prime equipment is upon failure only, it may be necessary to specify that new transducers must be implanted whenever the prime equipment is disassembled to the appropriate level. Bad transducers will sometimes be the cause for a false alarm repair on the prime equipment, but if such false alarms are kept infrequent, compared to properly diagnosed prime equipment failures, the use of the transducers can be justified. If the nature of the system permits, tests can be performed periodically for the purpose of checking the imbedded transducer performance. The records of such checks can become a calibration record for the devices, if there is a practical means to store the data and associate it with the test system.

11-5.4 USING THE TEST SYSTEM OPERATION MEASUREMENT DEVICES FOR TEST INTERFACE

If the test system is equipped with measurement devices which must be monitored during the normal operation of the system, the signals from these devices may be considered for interface to a test system. If this is to be successful, the designer must consider the nature of the test equipment interface. Signals must be of the type which can be presented to the test system (such as electrical analog or electrical digital). The test interface must isolate the test system such that errors in the connection of the test system will not damage the prime equipment. The decision to use a built in monitoring function for test monitoring as well could result in the selection of a different measurement technique. For example, temperature can be monitored with gas pressure bulb sensors, which will drive a display without the use of electrical signals. If the temperature is to be presented to an external test system, a different means of temperature sensing based on electrical signals might be selected at the time of design, to avoid the need to duplicate the measuring of the same function with two different types of sensors.

SECTION II

EQUIPMENT DEGRADATION

11-6 OVERHAULS

Overhauls are required to assure continued performance, arrest degradation, and restore operating systems to their specified operating conditions throughout their useful lives. The necessity for overhaul of mechanical equipment is inherent within the subsystem components themselves and is dependent upon their operational environment, the physical properties of the materials used to fabricate them and the processes used to protect them in their environment.

Manufacturers of equipment recommend overhaul intervals. The basis for their recommendations is derived from the failure history of similar components used in like applications, the results of dynamic testing of components, and the analysis of materials. Additionally, the manufacturer must facter in the elements of the new design that affect overhaul.

The new design may use materials and processes having little history by which an accurate overhaul estimate can be made. On the other hand, the materials and processes may have properties that appear to permit a state-of-the-art advancement in the equipment design. Some properties that affect overhaul intervals are wear, fatigue, corrosion, erosion, crystallization, and fracture. Materials that resist failures due to their being less susceptible to these factors are the most desirable for use in mechanical equipment design. The use of these materials should be on such a scale that an even distribution of degradation occurs within the equipment in the prescribed environment and operation. The use of materials with substantial differences in resistance properties will promote a condition wherein the life of the least resistant material establishes the overhaul interval. Less resistant materials have a place in the design and may be used effectively in applications where they are not subject to stress and wear and have finishes that provide resistance to galvanic corrosion and moisture.

The use of modular design permits a reduction in the complexity of overhaul tasks and an increase in intervals between overhauls.

This increase will be due primarily to the reduced number of components subject to environmental degradation; consequently, interval selection is less critical.

11-7 INSPECTION

Scheduled inspections to prevent and/or detect equipment degradation generally are performed by technicians, either by visual observations or with the aid of special equipment. Maintenance actions normally are initiated to correct deficiencies found during the course of inspection. Inspection thus provides the following benefits:

(1) Uncovers potentially hazardous conditions.

(2) Provides a means of identifying conditions that might prevent successful performance.

(3) Determines the effectiveness of corrosion control programs and other preventive maintenance tasks.

(4) Detects malfunctions of equipment subsystems, particularly of little-used modes of operation.

The inspection requirements can be justified readily when the benefits of inspection are considered and the consequences of failing to make the inspections are understood. Scheduled inspection, however, represents a significant maintenance load to the maintenance crew at the organizational level. Daily inspections, in particular, tax the capabilities of using units. In actual practice, technicians tend to concentrate on inoperative units. Thus, the inspections may be cut short or neglected. The designer, therefore, should incorporate design features that minimize the necessity of performing inspections and make inspection requirements as simple as possible.

Minimization of inspection requirements is achieved best by using inspection standards such as MIL-M-5096. In the development of new equipment, inspection criteria become the basis for preliminary inspection requirements. An inspection validation program provides a basis for decisions as to which requirements will be retained and which will be discarded. Additionally, the validation program can be used to identify new inspection requirements. The major task to be performed during the preliminary design period is to translate the inspection requirement criteria into preliminary inspection requirements. Criteria used for this purpose are:

(1) Inspections that will guard against hazards that could contribute to equipment damage and affect personnel safety.

(2) Inspections that insure that systems, assemblies and components checked or removed during the course of maintenance are

reinstalled properly.

(3) Inspections that will insure early detection and correction of defects.

(4) Inspections that will assure a thorough and continuing effort to minimize or prevent the development of corrosion and will assure the early recognition of corrosion-producing conditions.

(5) Requirements that will assure that inspection, test, replacement, etc., needed on a repeating basis are accomplished.

(6) Assurance that no inspection is required of items that are observed daily during equipment operation or that are monitored during operation (equipment that is automatically monitored by built-in test).

(7) Assurance that every inspection of components permits determination of component condition.

Simplification of inspections should be considered a design requirement. One of the most effective ways of simplifying inspection is to provide rapid, simple access to the area to be inspected. The techniques and criteria for attaining the necessary accessibility are discussed in detail in Chapter 10. Another means of simplifying inspection is to provide built-in inspection aids. For example, vehicle tires have been designed with inspection aids such as grooves or holes in the tread that, when worn to a specified level, indicate that the tire requires change. Hydraulic filters are designed with flag indicators that alert the inspector that they should be replaced or cleaned. Similar aids should be considered and incorporated whenever possible. The procedure of inspection itself provides a means of simplification. Inspection procedures should be written in simple syntax with a limited and consistent vocabulary and using a sequence of steps that yields the most effective use of maintenance time. The instructions for the preparation of inspection procedures and work cards have been standardized in MIL-M-5096.

11-7.1 INSPECTION SYSTEM MODELING

The U. S. Army has experienced a revolution in aircraft designs and configurations in the last several years, but this revolution has never been paralleled by a close study of new or better systems of preventive maintenance and inspection. In acknowledging the need for a scientific approach to the solution of this problem, the Department of the Army established Project Inspect (Ref. 3) to analyze aircraft maintenance scheduled inspections and to design an improved inspection scheme.

At the heart of the project is the MAVIS Model (Model for

Analysis of Vehicle Inspection Systems), a computer simulation of aircraft inspection, usage, and repair. The implementation of the optimum inspection scheme derived from this model has great potential for increasing inspection efficiency and operational readiness, reducing maintenance costs, and improving mission reliability.

The MAVIS model (Ref. 4) is structured to provide a systematic method for evaluating the effectiveness of alternate inspection concepts. It produces the simulated results and characteristics of an inspection concept on the basis of data input which supplies the component mix in the aircraft, component parameters, and a formal description of the inspection concept. These inputs are combined in a series of calculations which yield expected values for preventative repairs, failures, and maintenance man-hours for each component under the inspection scheme. This process is continued until all components comprising the aircraft configuration have been evaluated, and the expected values are then processed to provide a summary of selected indicators such as aircraft availability, reliability, etc. Comparison of results from different runs leads to model iterations with input parameters modified to investigate the impact of variation in significant areas. This iterative process is followed until sufficient information is available to allow selection of the optimum inspection concept.

After selection of the most effective system, the model provides capability for optimizing inspection intervals for individual components and balancing workload to individual scheduled inspection points.

11-8 DEGRADATION OF THE PRIME EQUIPMENT DUE TO IMBEDDED DEVICES

Placing a measurement device within a test system may in some cases adversely affect the reliability of the prime equipment. A flowmeter placed in a hydraulic line could be the cause of flow restriction, should the blade of the turbine become jammed. A pressure transducer can become a potential source for a hydraulic leak. However, the designer must consider the need for making the measurement relative to the life mission of the test system. If access to measurement is necessary, some form of physical interface will be necessary at the time of test. The prime equipment designer must determine if the reliability of the system will fare better from the hazards of the built in device or from the hazards of a maintenance operator disconnecting test system connections to make the necessary test connections.

SECTION III

MODULARITY, SIMPLIFICATION AND FUNCTIONAL PARTITIONING

11-9 GENERAL

System and equipment designs should incorporate features which enable cost effective maintenance support throughout a deployed hardware life. Such maintenance characteristics should be based on prescribed utilization concepts and should be fully compatible with the ultimately expected system densities, mission profiles and geographical dispersement patterns. Some examples of a maintainability design criteria are:

(1) All repair part items having the same part numbers should be functionally and physically interchangeable without modification of adjustment of the items or the system or equipment in which they are used.

(2) Maintenance adjustment or alignment should not be required.

(3) Preventive (scheduled) maintenance requirement, including calibration, should be eliminated.

(4) Physical and functional maintenance access should be provided to any active unit upon opening or removal of access entries, and should not require the prior removal or movement of other components.

(5) Devices securing access entrances and maintenance replaceable items should be the captive, quick-release type.

(6) Special (system or equipment peculiar) tools should not be required in the performance of user or intermediate level maintenance tasks.

Unless otherwise dictated by customer imposed constraints, the following should be defined by total system trade studies prior to initiation of detailed system or equipment design:

(1) A baseline maintenance concept.

(2) Primary and secondary fault isolation methods, quantitatively expressed in terms of failure rate percentages and callout resolution for each level of maintenance.

(3) The number and complexity of hardware levels comprising the system or equipment, with the lowest being consistent with a cost effective, discard-at-failure maintenance concept.

(4) The required degree of intersystem and intrasystem commonality at each hardware level.

(5) Whenever applicable, an optimized means of interfacing

mission and maintenance requirements with existing systems and equipment.

11-10 MODULARITY

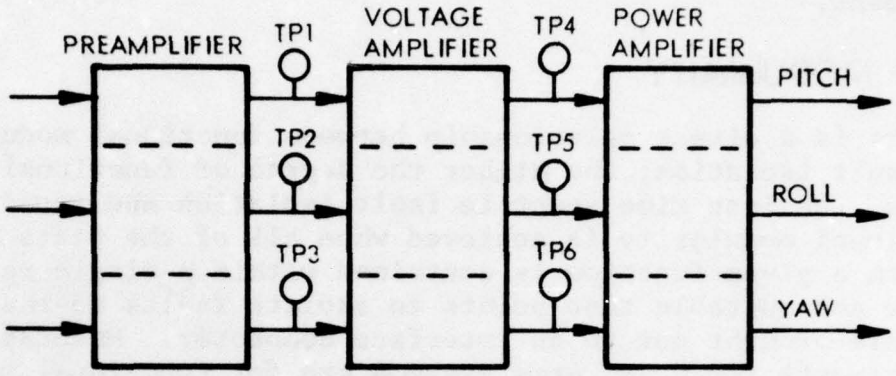
There is a direct relationship between functional modularity and fault isolation; the higher the degree of functional modularity, the less time spent in fault isolation and repair. Functional modularity is achieved when all of the parts associated with a given function is contained within a single replaceable module and suitable test points to isolate faults to that function are brought out to an interface connector. Maintainability requirements for U. S. Army systems are for functional modularization at all levels of assembly/disassembly. Theoretically, any test system can be divided into a number of packing levels. A distinguishing characteristic of each level is that it generally comprises components, assemblies and/or units with a common scheme of interconnection.

Although maintainability and reduced logistic costs are the prime motivation for modularized construction, there are other factors such as adaptability to new system requirements which tend to reinforce the argument for modularization. Development of modularized packaging concepts must take the following into account: fault isolation methods, module usage, updating requirements, relative number of interconnections, and physical size. These functional and operational parameters are strongly influenced by the packaging scheme and must be considered along with the purely physical aspects.

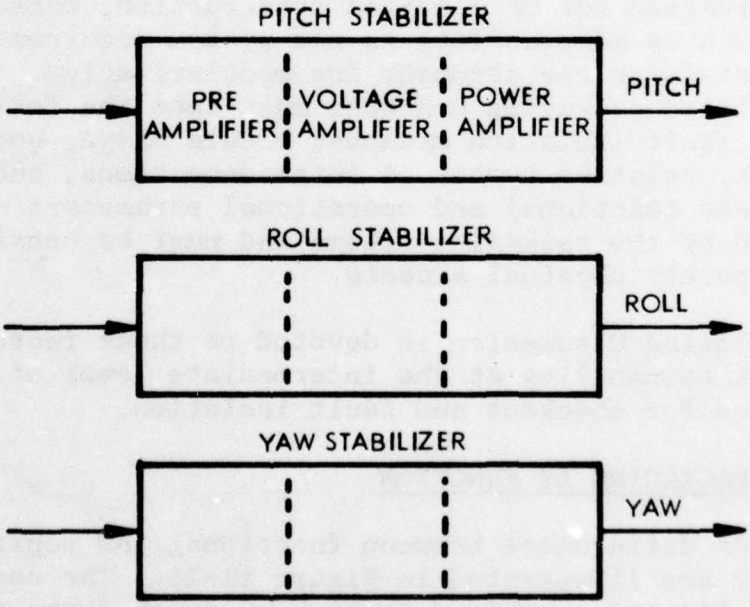
The following discussion is devoted to those factors that affect maintainability at the intermediate level of support when ATE is used for checkout and fault isolation.

11-10.1 PACKAGING BY FUNCTION

The major differences between functional and non-functional modularity are illustrated in Figure 11-11. The design in Figure 11-11(A) is packaged in such a way that the pitch, roll, and yaw signals are conditioned and amplified by three separate modules, namely, a preamplifier, a voltage amplifier, and a power amplifier. Each contains three independent identical channels, one for each different signal. If the performance level of a particular signal drops below a predetermined limit, then isolation to the faulty module is usually accomplished by measuring for specified values at appropriate test points, as shown.



(A) Non-Functional Packaging



(B) Functional Packaging

Figure 11-11. Functional and Non-Functional Packaging

A major advantage of this design is that individual modules can be readily built and tested in quantity by the manufacturer, and can be improved in reliability and size as state-of-the-art progresses. One major disadvantage is that separate test points must be provided for each individual module for purposes of fault isolation.

With the design in Figure 11-11(B), each signal channel is packaged functionally, so that the associated preamplifier, voltage amplifier, and power amplifier are all mounted on the same module. In this case, if each module is a throwaway, then no test points are necessary for fault isolation.

11-10.2 RELATIVE NUMBER OF INTERCONNECTIONS

As the physical size and number of functions per unit decrease, the total number of interconnections between SRA's and the number of connectors increases. As the number of connectors and interconnections in the system increases, reliability decreases. Illogical packaging can also result in an excessive number of interconnections between modules (Figure 11-12).

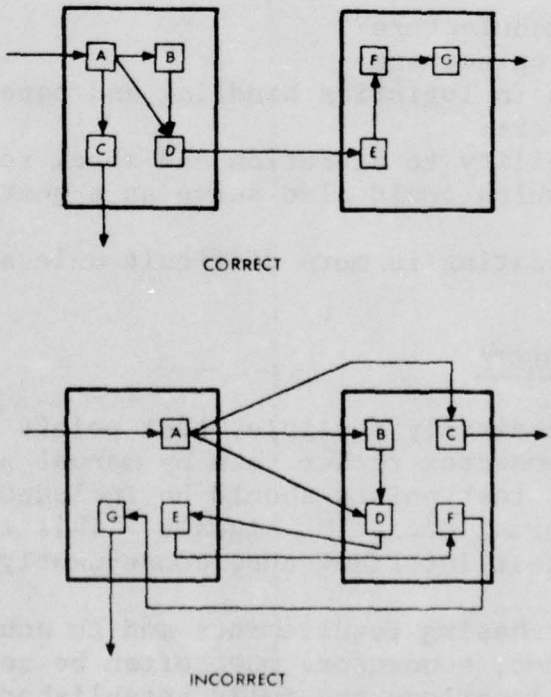


Figure 11-12. Classical Example of Illogical Packaging, Resulting in Excessive Interconnections

Reliability is dependent on the failure rate per contact and the total number of connections in the system. This failure rate is governed by such factors as: the type of connection, quality control, and operating environment. Although failure rates for individual connections are extremely low, the great quantity of connections in a test system can contribute significantly to the overall system failure rate.

11-10.3 PHYSICAL SIZE

Permissible sizes for components are generally determined by system requirements, space dimensions and maximum weight limits. The component size, in turn, establishes overall dimensions for internal units. As a rule, components and units should be capable of easy and safe handling by one man. They should be easily replaced without excessive insertion and extraction forces, and should have adequate heat dissipation, as required.

Advantages of large components are:

(1) More units per components and, hence, ease of functional modularization, therefore fewer test points

(2) Fewer interconnections between units and, hence, greater reliability

(3) Ease of manufacture

(4) Ease of replacement

(5) Reduction in logistics handling and paperwork.

Disadvantages are:

(1) Susceptibility to vibration and shock requires additional reinforcement (which could also serve as a heat transfer mechanism)

(2) System updating is more difficult unless provisions are made beforehand.

11-10.4 TEST POINTS

When it is technically feasible, test points must be accessed directly at a connector rather than by manual probing. If density permits, test points should be included on the same connector as the normal operating signals. This technique greatly simplifies the test interface and, consequently, fault isolation.

Because of purchasing requirements and to achieve a degree of standardization, connectors must often be selected long before test point locations are fully established. As a general rule, the number of pins on a connector must be increased by some 25 percent to accommodate the additional test points needed for automatic fault isolation within repairable assemblies. If

connector sizes cannot be increased conveniently to accommodate the additional test points, provision should be made for mounting a separate test connector on the component surface. A protective cap must be provided for environmental protection. The need for removal of cover plates or any other form of disassembly to reach a test connector should be avoided.

11-10.5 IN-PLACE REPAIRABLE ASSEMBLIES

The least desirable form of packaging is an in-place repairable assembly which cannot be replaced as a complete unit but which must be repaired while installed in the component. Power supplies, electromechanical units, and electro-optical assemblies often fall into this category.

In-place repairable assemblies add significantly to both test and repair time. Test time is increased because faults isolated to the in-place repairable assembly must be further isolated to the unit.

The additional step for removal of plug-ins is normally required because of the added test access required for unit fault isolation. The best solution to this problem is to replace the entire in-place repairable assembly with plug-in assemblies.

11-10.6 ADJUSTMENTS AND CONTROLS

One of the major goals in design for ATE compatibility is the elimination of manual adjustment and trimming controls in circuits. In practice, fixed interface is difficult to achieve, and total elimination of such controls cannot be expected in all test systems.

All adjustments that cannot be eliminated must be designed for accessibility and ease of adjustment by maintenance personnel. There should be no need for the removal of cover plates or other mechanical structures to gain access. A simple standard alignment tool or screwdriver should be all that is necessary to make an adjustment. Specially designed tools or holding fixtures should not be required. Furthermore, all controls and adjustments should be clearly labeled and be mounted on the side of the assembly that faces the maintenance man or ATE operator.

11-11 FAILURE MODE ANALYSIS

In the past, most design engineers did not consider testing a device until after an engineering model or prototype had been

built. Then, the physical characteristics of the model or prototype were transferred to production drawings with no additional effort devoted to design for testability, usually due to schedule and dollar limitations. To insure optimum maintainability, test design must be included as part of the system design, hardware design, and software design and conducted in parallel with the other essential design functions. Maintainability design should receive equal or greater emphasis than reliability design, as most materiel, regardless of reliability, will fail during its service life. If the materiel is not designed as a throw away item, then it must be inspected, tested, and repaired after failure.

The three most important related questions that a design manager should ask upon assigning a design task to an engineer are:

- What are the equipment failure modes?
- What are the most probable causes of each failure mode?
- What are the indications of failure and how does one determine the specific cause of each probable failure?

The design cannot be considered complete until satisfactory answers have been provided for each of these questions. The test accessibility design handbook includes methods and procedures for performing a failure mode analysis on mechanical, hydraulic and pneumatic equipments. Failure mode analysis is combined with a procedure called Test Requirements Analysis (TRA) when ATE will be used in the maintenance process. The typical steps involved are listed as follows:

(1) Identify dominant failure modes of pertinent parts and assemblies.

(2) Relate the effect of these failures to equipment safety, operation, and maintenance requirements.

(3) Determine relative frequency of occurrence of the unit failures from historical records and engineering design data.

(4) Select candidate faults to be addressed for development of diagnostic and prognostic test techniques.

(5) Identify parameters which exhibit sensitivity to the above failures.

(6) Based on the component's operating principles and physics of failure, develop diagnostic rationale and decision rule hypotheses, including:

(a) Other parameters which must be correlated with the selected fault parameters.

(b) Equipment operating regimes to which the diagnostic rationale applies.

11-11.1 TEST ACCESSIBILITY CONSIDERATIONS

Along with failure mode and test requirements analysis, physical test point and other accessibility considerations are important for mechanical, hydraulic and pneumatic equipments.

Access for the inspection, testing, servicing and repair of mechanical and other non-electronic equipments has been covered extensively in the literature. The majority of studies defining access requirements have been sponsored either by the military services or the commercial airlines. Chapter 10 contains a list of questions in checklist form as an illustration of one method of analyzing a mechanical design for accessibility.

Test point accessibility and selection also involves consideration of transducer location and associated wire routing for mechanical, hydraulic and pneumatic automatic testing. MIL STD-1326 specifies a test point selection philosophy and justification criteria.

11-11.2 ANALYSIS OF NEW-DESIGN MATERIEL

Test accessibility analysis of new materiel should be part of the overall maintainability and support cost effectiveness analysis. In general, this analysis is summarized as follows:

(1) Determine failure modes. For each failure mode, determine effect of failure on planned missions, describe symptoms of each failure mode, determine probable causes of each failure mode, and estimate probability of occurrance of each failure mode and/or cause of failure.

(2) Estimate cost of repair for each failure mode and cause. Include fixed costs of test procedure design, test access design, additional cost of prime equipment, test equipment, test accessories, and maintenance manuals; recurring costs of spare parts, training, and test and repair labor. If repair cannot be economically justified, do not prepare test procedure or provide test access design.

(3) Where repair can be economically justified, provide test access.

11-12 INTERFACE DESIGN

Design of the interface between the ATE and the system, component or unit to be tested is an important and necessary part of the test design process because it resolves compatibility problems. Currently, all multi-purpose ATE systems utilize some sort of general purpose interface to adapt and augment the

ATE in order to test a broad spectrum of items. Interface adapters have become so widely used that they are often considered an inherent part of the ATE system, whereas in fact they are part of the software package. The interface design process is shown in Figure 11-13.

Ideally, the interface should contain only adaptive connectors and cables. However, there are a number of reasons why active and passive elements also become necessary:

(1) All interface requirements are not obvious during the initial development of ATE building blocks.

(2) ATE systems are usually designed with a general-purpose interface adapter chassis to handle, with minimal adapting, all test requirements.

(3) It is impractical to add a special signal conditioner or other device to an ATE system merely to satisfy a single test requirement.

(4) ATE and test hardware specifications change after the ATE system is designed.

(5) Test requirements for existing units change after the ATE system is designed.

(6) The ATE must support new equipment not considered originally.

(7) Many units are not designed to optimize ATE testing.

Though interface adapters can increase the flexibility of ATE systems by allowing them to test a broader spectrum of signals with more accuracy and sensitivity than originally envisioned for the ATE, they should not be considered as the natural solution of difficult test problems. Instead, alternate testing techniques should be explored first, followed by maintenance system trade-offs.

11-13 COMPATIBILITY

This paragraph contains checklists applicable to scoring compatibility tasks. The checklists contain questions relating to common ATE compatibility design parameters, and the questions have been ordered in a logical sequence to facilitate scoring. Task scores are obtained by totaling the individual question scores.

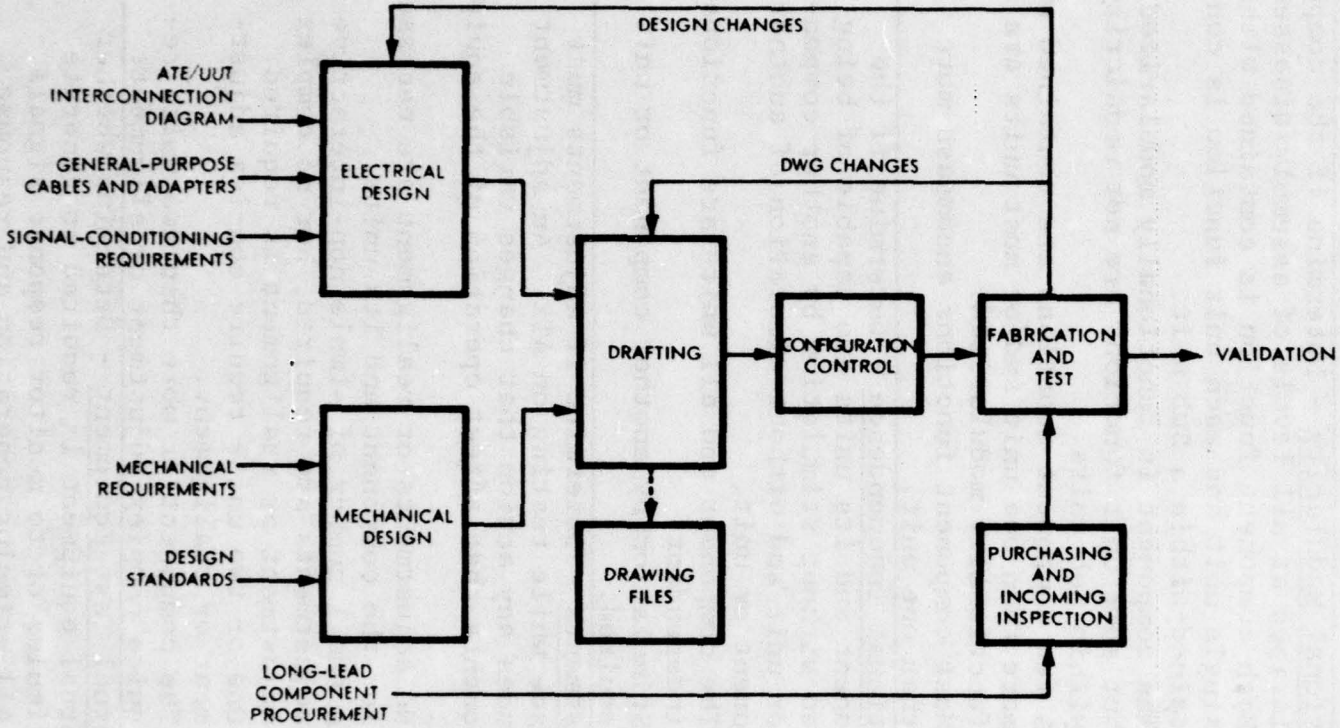


Figure 11-13. Interface Design Process

TABLE 11-3. CHECKLIST A - ATE COMPATIBILITY

Item	Criteria	Score
1	Functional Modularity - Determine if the component modularized at all levels of assembly/disassembly.	
	(a) Each component function is contained within a single unit and each unit function is contained within a Sub unit.	4
	(b) The component is functionally modularized, but some unit functions are not modularized within Sub units.	3
	(c) A few component functions are contained on more than one unit and/or most units are not functionally modularized.	2
	(d) Most component functions encompass more than one unit.	0
2	Functional Independence - Determine if the component and its units are capable of being tested without stimulation by another component or unit and without simulation of another component or unit.	
	(a) The component and all units are functionally independent.	4
	(b) Stimulation by another component or unit is required.	0
3	Adjustments - Determine if adjustments must be made while testing on ATE. An adjustment includes any action that changes variable components that affect operation of the equipment.	
	(a) No adjustments or realignment are necessary for the component and its units.	4
	(b) A small number of simple non-interactive adjustments are required, but no complex adjustment or realignment is required.	3
	(c) One or two units require complex adjustment or realignment.	2
	(d) The component or more than two units require complex adjustment or alignment.	0
4	External Test Equipment - Determine whether external equipment is required to generate a stimulus or to monitor response signals.	
	(a) All stimulus generation and response monitoring can be accomplished by the ATE.	4
	(b) External test equipment is required.	0

TABLE 11-3 CHECKLIST A - ATE COMPATIBILITY (Continued)

Item	Criteria	Score
5	Environmental - Determine if the component or the units require special environmental considerations during test on ATE, such as vacuum chambers, oil baths, shake tables, ovens, cooling air, screen rooms, etc.	
	(a) No special environment is required.	4
	(b) Forced air cooling or an electromagnetically shielded enclosure is required.	2
	(c) Other special environment conditions are required.	0
6	Stimulus and Measurement Accuracies - Determine the stimulus and measurement accuracies required for high confidence test.	
	(a) All tests can be performed on ATE at high confidence levels; i.e., stimulus is adequate and measurement is at least ten times more accurate than the tolerance on the component to be tested.	4
	(b) Measurement is at least three but not more than ten times as accurate than the tolerance of the component to be tested.	3
	(c) Measurement is between one and three times more accurate than the tolerance of the component to be tested.	1
	(d) Stimulus and/or measurement accuracy is inadequate.	0
7	Test Point Adequacy - Determine if sufficient test points are provided for non-ambiguous fault isolation and for monitoring redundant circuits and BIT circuits.	
	(a) Redundant and BIT circuits can be fully tested and test points at the output of each functional circuit permit direct non-ambiguous fault isolation.	4
	(b) Indirect (non-signal tracing) troubleshooting and/or ambiguous fault isolation is necessary.	3
	(c) Redundant and BIT circuits not tested or there is excessive ambiguity.	0

TABLE 11-3. CHECKLIST A - ATE COMPATIBILITY (Continued)

Item	Criteria	Score
8	Test Point Characteristics - Determine test point impedance and voltage levels.	
	(a) Voltage is less than a selected value and impedance is compatible with ATE interface. Component test points will drive up to ten feet of coaxial cable.	4
	(b) Voltage dividers and/or passive and simple active impedance transformation are required.	2
	(c) Waveshaping and/or signal transformation is required.	0
	Total Checklist score	

TABLE 11-4. CHECKLIST B - MAINTAINABILITY

Item	Criteria	Score
1	Access - Determine if internal access is adequate for visual inspection and manipulative actions.	
	(a) Access is adequate for both visual inspection and manipulative tasks in subassembly or unit repair, due to internal construction and part location.	4
	(b) Access is adequate for visual inspection, but not for manipulative tasks.	2
	(c) Access is adequate for manipulative tasks, but physical location does not easily permit visual inspection.	2
	(d) Access is not adequate for visual inspection or manipulative tasks.	0
2	Packaging - Determine accessibility (within subassembly) to failed components or parts requiring mechanical disassembly.	
	(a) Internal access to components and parts can be made within one minute, with no mechanical disassembly.	4
	(b) Little disassembly is required (less than three minutes).	2
	(c) Considerable disassembly is required (more than three minutes).	0
3	Replaceability of Failed Elements - Determine the manner in which failed elements (e.g. assemblies, components, parts) are removed or replaced during the maintenance action.	
	(a) Units or parts are of plug-in nature with a simple restraining mechanism.	4
	(b) Units or parts are of plug-in nature and mechanically held by fasteners that are not of the quick connect/disconnect variety.	2
	(c) Units are of solder-in nature so that removal requires unsoldering of part terminations.	2
	(d) Units are of solder-in nature and mechanically held.	0

TABLE 11-4. CHECKLIST B - MAINTAINABILITY (Continued)

Item	Criteria	Score
4	Safety (Personnel) - Determine if the maintenance action requires personnel to work under hazardous conditions such as close proximity to high voltage, radiation, moving parts, or high-temperature components, etc.	
	(a) Task does not require work to be performed in close proximity to hazardous conditions; no precautions necessary.	4
	(b) Some delay is encountered because of precautions necessary to neutralize unsafe conditions.	2
	(c) Considerable time is consumed because of special precautions required to avoid hazardous conditions.	0
5	Labeling - Determine if elements (e.g., components, assemblies, units, etc.) associated with the maintenance actions are adequately identified.	
	(a) All elements are labelled with full identifying information, and all identifying information is clearly visible.	4
	(b) All elements are labelled with full identifying information, but some information is not visible.	2
	(c) All information is visible, but some elements are not fully identified.	2
	(d) Some information is not visible and some elements are not fully identified.	0
6	Latches and Fasteners - Determine if screws, clips, fasteners, or latches within the unit require special tools.	
	(a) Latches and fasteners are: (1) captive, (2) need no special tools, and (3) require only a fraction of a turn for release.	4
	(b) Latches and fasteners meet two of the above three criteria.	2
	(c) Latches and fasteners meet one of the above criteria.	1
	(d) Latches and fasteners meet none of the above criteria.	0

TABLE 11-4. CHECKLIST B - MAINTAINABILITY (Continued)

Item	Criteria	Score
7	Connector Standardization - Determine the number of different connector types and sizes used on the component and units.	
	(a) MIL-C-26482 connectors are used on the component, all units use one connector size.	4
	(b) Quick-disconnect connectors intermateable with MIL-C-26482 are used on the component; all units use one connector size.	3
	(c) The component has quick-disconnect connectors, but various connector sizes are used on units.	2
	(d) Connectors are not limited to one type, or quick-disconnect types are not used. Units are not plug-in.	0
8	Connector Keying and Accessibility - Determine if component connectors are keyed to preclude inserting any connector into the wrong receptacle, and are readily accessible for quick connection and removal.	
	(a) Connectors meet both criteria.	4
	(b) Connectors meet one of the above criteria.	2
	(c) None of the two criteria are met.	0
	Total Checklist score	

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2. MIL-STD-415D, Test Provisions for Electronic Systems and Associated Equipment, Design Criteria for, 8 October 1971

3. USAAMRDL-TR-76-27, Project Inspect Final Report, Eustis Directorate, U. S. Army Air Mobility R&D Laboratory, Fort Eustis, Virginia 23604, 1976

4. USAAMRDL-TR-72-35, Analysis of Army Helicopter Inspection Requirements, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, Sept. 1972

AD-A040 129 RCA GOVERNMENT SYSTEMS DIV BURLINGTON MASS AUTOMATED--ETC F/G 15/5
TEST ACCESSIBILITY DESIGN GUIDE FOR ARMY MECHANICAL, HYDRAULIC --ETC(U)
SEP 76 F W HOHN, K G HOPKINS, R C BLANCHARD DAAA25-75-C-0681
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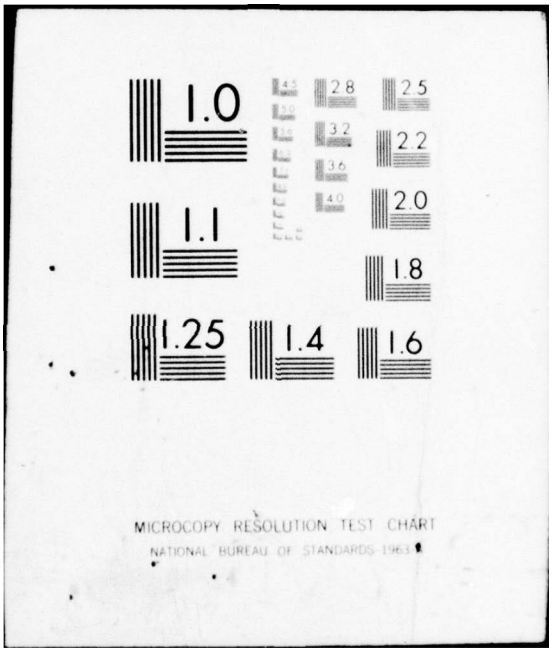
1.0
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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963

CHAPTER 12
MEASUREMENT PRACTICES

12-1 INTRODUCTION

This chapter is included to acquaint the designer with the various techniques employed, primarily in fluid systems, for the measurement of pressure, temperature and flow-rate on which the operation of the ATE depends for its input.

Because of the difficulty of making the flow-rate measurement in most fluid systems, this subject has received special emphasis.

Special measurement techniques for particulate contamination in fluid systems is also included.

12-2 PRESSURE MEASUREMENTS USING PRESSURE-TO-ELECTRICAL TRANSDUCERS

Transducers for the transformation of pressure into an electrical signal take many forms. The sensing mechanisms alone include many shapes as:

(1) Flat diaphragm
(2) Corrugated diaphragm
(3) Bellows
(4) Straight tubes (expanding diametrically with pressure)
(5) C-shaped Bourdon tube
(6) Twisted Bourdon tube
(7) Helical Bourdon tube
(8) Spiral Bourdon tube

Additionally, the means for converting the various physical strains generated by these sensing mechanisms into electrical outputs are varied:

(1) Potentiometric
(2) Vibrating element (FM output)
(3) Inductive (FM output)
(4) Reluctive
(5) Magnetroresistive (Hall effect)
(6) Capacitive
(7) Resistive
(8) Strain-gage
(9) Solid-state-sensitive substrate
(10) Piezolectric

12-2.1 THE STRAIN GAUGE TRANSDUCER

Of the above choices, in the measurement of fluid pressure in the range of 20 psig to 5000 psig, the most often encountered configuration in hydraulic test systems is the strain-gauge transducer using a diaphragm (flat or corrugated) or a straight tube as the sensing mechanism. These transducers most often develop a low-level dc signal (10 to 30 mv) which must be amplified to usable levels externally. There are an increasing number of transducers offered, however, which contain an integral dc amplifier whose output measures 5 VDC maximum.

The strain-gauge transducer also offers good dynamic response for two reasons:

(1) Cavity volume is typically less than 1 $inch^3$.

(2) Rate-of-change of volume with pressure change is small resulting in negligible fluid flow down the measurement line during transient pressure measurements.

Typical overall accuracy is 0.5 to 1 percent of full scale with error sources apportioned as listed below in Table 12-1.

TABLE 12-1. TYPICAL ERROR SOURCES IN STRAIN-GAUGE TRANSDUCERS

Non-linearity	% F.S.	0.1 to 0.15
Zero shift due to temperature	% F.S.	0.25 to 100°F
Hysteresis	% F.S.	0.05 to 0.10
Scale factor change due to temperature	% F.S.	0.35 per 100°F
Repeatability	% F.S.	0.03

It is easy to see that temperature effects can make the difference between a 1/2 percent accuracy and a 1 percent accuracy.

The strain-gauge bridge must be provided with a carefully regulated power supply. Both ac and dc can be used as the signal source, and the measurement output will be a small fraction of the input signal, as caused by the unbalance of the bridge when the pressure is applied to the sensing diaphragm. If an ac source is used, both power source and measurement output can be transformer coupled, and access to rotating assemblies can be accommodated. However, the measurement of an ac signal is subject to greater errors than in dc signals, because of the effects of distortion in the signal, and nonlinearities in the ac detector. In all cases,

the output signal is a fixed fraction of the input power reference, and a typical strain gauge device may be rated as 3 mv/volt full scale. This means that full scale output of the gauge will be 30 millivolts if a 10 volt power reference is applied, which is a typical reference level. The accuracy of the transducer is directly affected by any drift in the power reference, that is a 1 percent change in the reference will result in a 1 percent error in the measurement. In typical manual test installations, each strain gauge transducer may be supplied with its individual power reference, and that reference is adjusted (slope and offset) to calibrate the gauge. In centralized automatic test systems, a single reference source may be used for all strain gauges, and the power supply voltage itself will be measured to assure that drift has not occurred, or possibly to be factored into the calibration calculation. Calibration in an automatic system will usually consist of computer-process numerical calculations applied to the measured voltage, and the test system will have computer-stored calibration constants for each device.

Finally, one may not expect to overload a strain gauge transducer indefinitely without damage, and a typical tolerable overload is two times rated output with no more consequence than a minor zero-shift. If greater overloads can occur during use, a gauge protector is often used in the measurement line.

12-2.2 THE SOLID STATE SUBSTRATE

An increasingly important class of pressure transducer is made using integrated circuit technology to deposit a strain-sensitive circuit on a substrate. These units have the following advantages:

(1) Smaller than the strain-gauge devices (as small as 0.030 inch diameter in the extreme).
(2) Substantially lower cost
(3) Very wide bandwidth
(4) Higher output (without additional amplification)

They are not, at present, capable of the accuracy of a top-quality strain-gauge transducer since they exhibit factors of 2 to 5 times greater errors, at best, than those listed in Table 12-1. Nevertheless, they demonstrate considerable promise and, it is expected, that in some less demanding test systems, they will largely displace the strain gauge transducer.

12-2.3 THE SMOOTHING OF PRESSURE DATA

System-generated pressure fluctuations which are unwanted in the final data record are considered to be pressure noise. There are

two commonly used methods for smoothing these fluctuations before recording:

(1) Hydraulic Smoothing - This is normally accomplished by the use of a line restriction (sometimes called a gauge-damper) between the measuring tap and the transducer.

(2) Electronic Signal Processing - Either analog or digital processing is employed to extract the lower frequency components and reject the higher.

Hydraulic smoothing is unreliable. Its effectiveness is variable depending upon:

(1) The volume of entrapped air that exists beyond the line restriction.

(2) Whether or not the restriction itself is passing liquid or gas (entrapped air)

(3) The nominal pressure being measured.

Even without the line restriction, excessive entrapped air in the measurement line will frustrate attempts to measure fast-moving pressure variations by applying a simple-lag hydraulic filter due to line-loss combined with the entrapped air cushion.

Furthermore, when used to monitor some sensitive hydraulic servos (as in aircraft fuel controls), the attachment of such an air-loaded line can send an otherwise stable servo into instability.

Consequently, it is good practice to:

(1) Avoid restrictions in the measurement line for the purpose of hydraulic damping.

(2) Provide a bleed for entrapped air as close to the transducer cavity as possible and at the high point of the measurement line.

(3) Introduce electronic smoothing of the pressure signal, either analog or digital as desired, if it is found necessary to reject high frequency components of the signal.

One circumstance in which hydraulic smoothing should be attempted is in cases where the pressure noise fluctuations are so large as to drive the transducer into a non-linear region such that subsequent electronic filtering then yields a signal artificially biased by such action.

Accordingly, if a carefully controlled gas volume can be arranged (as in a suitable accumulator) near the transducer, then a repeatable hydraulic filter may be realized by introducing a line restriction and purging most free air from the measurement line (to the point that the remaining air mass is small compared to that within the accumulator). This will produce a simple-lag function between the pressure at the measurement tap and the pressure signal from the transducer whose time constant rises with increasing line restriction and gas volume. (Strictly speaking, the function

is a simple-lag only for small pressure fluctuations around the operating point because. for large excursions, the adiabatic expansion and contraction of gas in the accumulator is non-linear).

12-3 THE MEASUREMENT OF FLUID FLOW

As in the measurement of pressure, there are a number of different schemes employing various physical effects that have been utilized for the measurement of fluid flow. A typical listing follows:

(1) Differential pressure techniques (measured across a restriction)
(2) Rotameter (variable area device)
(3) Ultrasonic device
(4) Velocity-head force measurement (strain-gauge on target)
(5) Hot-wire device (resistance bridge)
(6) Electromagnetic flow transducer (conductive fluids)
(7) Turbine flowmeter
(8) Pivoted fluid momentum device

Of these, the turbine flowmeter has been most widely used in hydraulic test stands. However, differential pressure techniques hold promise for automated testing as discussed in the following sections.

12-3.1 THE TURBINE FLOWMETER

This device is used extensively today in the measurement of fluid flow. One of its greatest attributes is that, unlike most measurement techniques, its errors are small and constant as a percent of measured flow (rather than maximum rated flow) down to very small values of flow. This device is relatively expensive, however.

12-3.2 THE INFLUENCE OF REYNOLDS NUMBER IN FLOW MEASUREMENT

In the following section, a discussion of various techniques of flow determination using pressure-drop measurements is presented. The success of these methods depends upon constraints on the numerical value of the dimensionsless parameter called Reynolds number. This number represents the ratio of inertial forces withing the moving fluid to viscous forces within the fluid and is computed as:

$$\text{Reynolds' No. } -(R_e) = \left[\frac{VD}{\frac{\mu}{\rho}}\right]$$

where

V = velocity of fluid (ft-sec^{-1})

D = I.D. of the fluid conduit (ft)

μ = fluid viscosity (slugs-ft^{-1}-sec^{-1})

ρ = fluid mass density (slugs-ft^{-3})

The property (μ/ρ) is defined as the kinematic viscosity, γ, with units of ft^2-sec^{-1} in the English system.

Since kinematic viscosity is often given in centistokes, the conversion is: 1 centistoke = 1.076×10^{-5} ft^2-sec^{-1}.

12-3.3 NOZZLE OR ORIFICE FLOW MEASUREMENT

The measurement of fluid flow rate by using the pressure drop across a nozzle or orifice is common where the requirements for accuracy are modest (1 to 5 percent). This is generally accomplished by using special flanges to hold the nozzle or orifice plate which contain, as an integral part, the two pressure taps needed for the differential pressure measurement. (See Figures 12-1 and 12-2 for a sketch of the arrangement for corner taps and flange taps, respectively.)

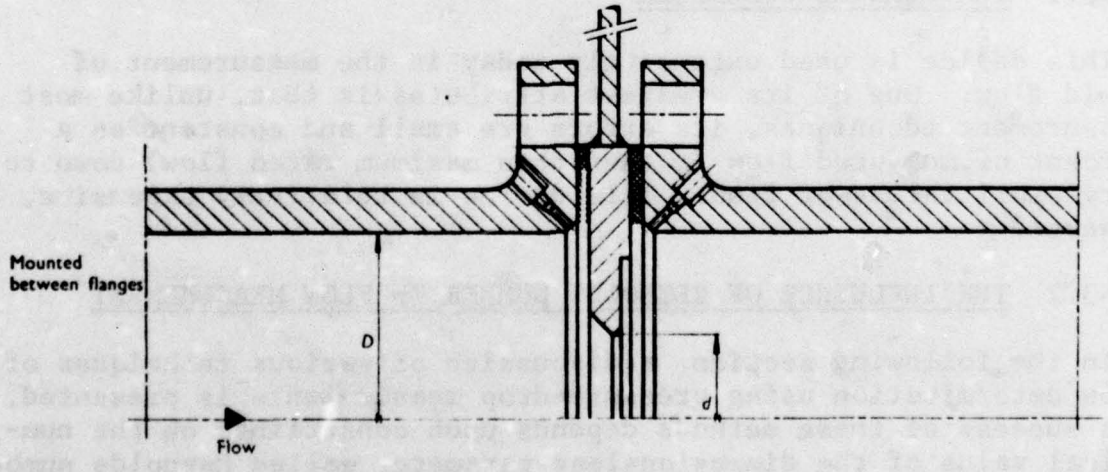


Figure 12-1. Corner Taps

12-3.4 FUNDAMENTAL EQUATION

The basic equation which relates the rate of fluid flow (q) with the measured pressure drop (ΔP) is:

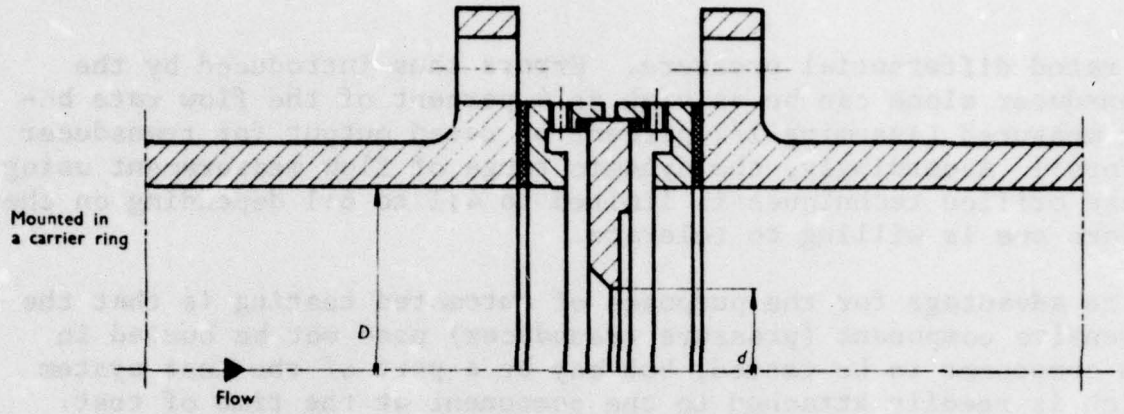


Figure 12-2. Flange Taps

$$q = CA_o \sqrt{\frac{2\Delta p}{\rho}}$$

where

q = fluid flow in ft^3-sec^{-1}

A_o = orifice cross-sectional area (ft^2)

Δp = measured pressure drop (lb-ft^{-2})

ρ = mass density of fluid (slugs-ft^{-3})

C = flow coefficient (not necessarily constant with changing flow; in consistent units)

Clearly, the smaller the pressure drop that can be measured accurately, the less is the restriction that must be introduced in the line as an orifice to achieve a flow measurement.

12-3.5 LIMITS ON DYNAMIC RANGE OF FLOW MEASUREMENTS

At the present time, the state of the art in off-the-shelf strain gauge differential pressure transducers provides full-scale ranges of as little as ± 2 psid with measurement accuracy of 1/2 to 1 percent of full scale.

It is to be noted from above, however, that the flow versus pressure-drop relation is square law and so, attempts to measure flow at, for example, 25 percent of the maximum flow for which the orifice is designed will yield pressure drops of only 6.25 percent

of rated differential pressure. Errors thus introduced by the transducer alone can be as high as 4 percent of the flow rate being measured (assuming 1/2 percent of rated output for transducer errors)! Accordingly, the dynamic range of flow measurement using these orifice techniques is limited to 4:1 to 6:1 depending on the errors one is willing to tolerate.

The advantage for the purposes of automated testing is that the expensive component (pressure transducer) need not be buried in the component to be tested, but may be a part of the test system which is readily attached to the component at the time of test. Only the orifice plate and its holder with pressure taps is required to be provided as integrated test components.

Furthermore, to extend the dynamic range of flow measurement, the test equipment designer may include a lower range transducer which is switched into the orifice taps for a low-scale flow measurement.

In contrast to the pressure drop down a uniform diameter pipe, nozzles and orifices exhibit a local pressure drop that is several times that which exists across two points which are located well upstream and well downstream of the restriction (this pressure drop taken at widely separate points is called the residual drop of the device because it represents the unrecoverable energy that is lost from the fluid and is smaller for nozzles than for orifices). This local effect increases the sensitivity of the device to flow changes and so makes the nozzle or orifice preferable from the aspect of minimum energy loss to the use of a straight-pipe pressure-drop measurement.

The use of conventional designs of nozzles and orifices in flow measurement is limited by:

(1) The computation of flow rate from pressure drop is simple provided the orifice discharge coefficient is constant. This is true only for high Reynolds numbers (roughly 100,000). Below this value, the discharge coefficient is itself a function of the Reynolds number and the computation of flow rate is considerably more complicated down to a Reynolds number of about 8000.

(2) Between a Reynolds number of 8000 and 2000, a transition occurs between turbulent and laminar flow and, as a consequence, reliable values of the discharge coefficient are not available, except under special conditions described below.

Fortunately, some recent work in England has produced two orifice designs that are capable of reasonable (5 percent) flow measurement accuracy of Reynolds numbers extending from 25 right up to 60,000, including, of course, the transistion region (Reference 1). These shapes are:

(1) The quarter circle orifice
(2) The conical entrance orifice

These are shown as Detail A and Detail B, respectively in Figure 12-3.

12-3.6 THE CONICAL ORIFICE

The following are the principle constraints on the use of a conicle orifice as a flow measuring device:

(1) Minimum pipe inner diameter = 1/2 inch (Reference 2)
(2) Permissible range of orifice diameter/pipe diameter ratio (β) = 0.10 to 0.30
(3) Useable Reynolds number range:
    25 to 20,000 for β = 0.1
    50 to 40,000 for β = 0.2
    75 to 60,000 for β = 0.3
(4) Minimum upstream, downstream open line = $\pm$3 pipe diameters
(5) Corner-tapped flanges are recommended.

12-3.7 THE QUARTER-CIRCLE ORIFICE

The quarter-circle orifice provides flow measurement over a somewhat different Reynold's number regime than the conical orifice as follows:

(1) Minimum pipe inner diameter = 1/2 inch (Reference 2)
(2) Permissible range of orifice/pipe diameter ratio (β) = 0.25 to 0.60
(3) Useable Reynolds number range:

β	R_e
0.30	300 to 100,000
0.40	500 to 150,000
0.50	1000 to 200,000
0.60	3300 to 250,000

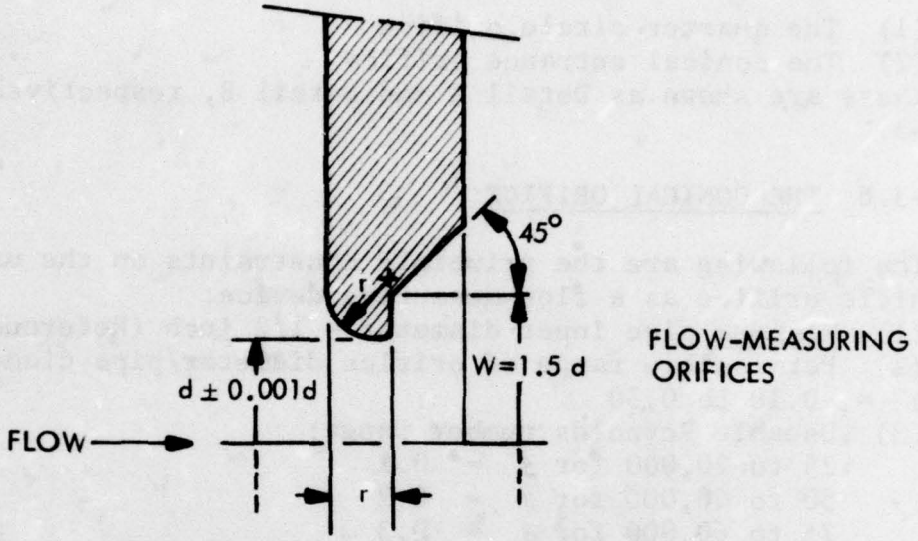
(4) Minimum upstream, downstream open line: $\pm$3 pipe diameters
(5) Corner taps are recommended

12-3.8 SAMPLE CALCULATION

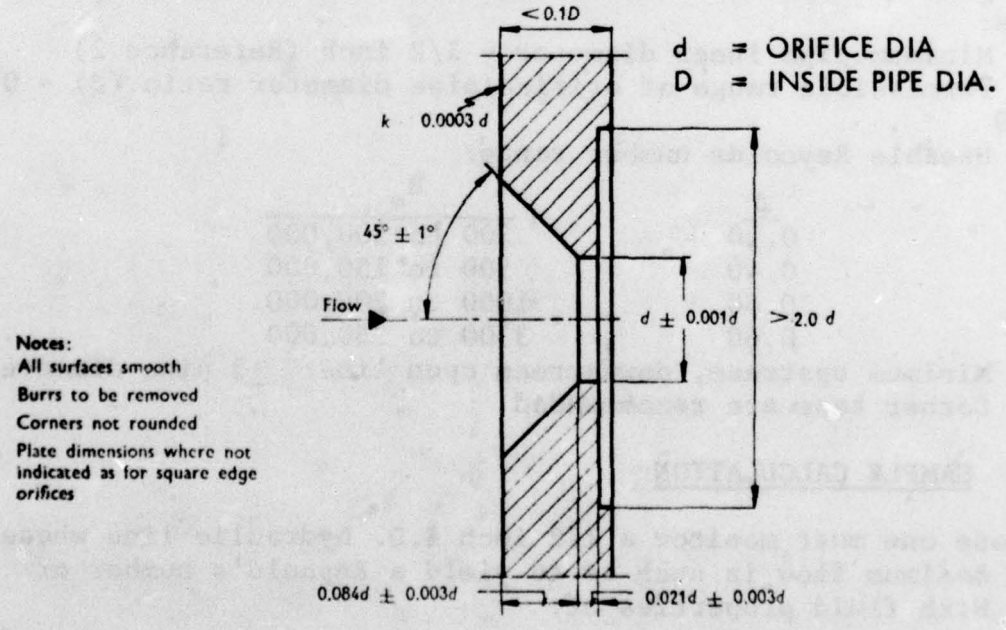
Suppose one must monitor a 1/2 inch I.D. hydraulic line whose design maximum flow is such as to yield a Reynold's number of 2000. With fluid properties of:

Mass Density (ρ) = 1.645 Slug-ft^{-3} (water is 1.935 Slug-ft^{-3})

Kinematic Viscosity (γ) = 10 ctks (= 0.0001 ft^2-sec^{-1})



DETAIL A - QUARTER CIRCLE ORIFICE



DETAIL B - CONICAL ENTRANCE ORIFICE

Figure 12-3. Flow Measuring Orifices

One may compute the flow velocity as:

$$V = \frac{\gamma R_e}{D_1} = \frac{(0.0001)\ (2000)}{\frac{0.5}{12}} = 4.8 \text{ ft-sec}^{-1}$$

and flow rate is:

$$q = A_1 V = \frac{\pi}{4} \left(\frac{0.5}{12}\right)^2 (4.8) = 6.55 \times 10^{-3} \text{ft}^3\text{-sec}^{-1}$$

or 2.94 GPM

Now, if we use one of the pressure transducers currently available in a range of ± 3.6 psid (± 100 inches of H_2O), we must compute the β ratio needed from the following equations assuming we will employ a quarter-circle orifice:

$$q = CA_o \sqrt{\frac{2\Delta p}{\rho}}$$

and

$$\beta = \frac{A_0}{A_1}$$

where

C = discharge coefficient (Reference 2)

A_0, A_1 = orifice and pipe - I.D. areas respectively

Δp = assumed pressure drop

ρ = mass density of fluid

q = flow rate

Rearranging these equations yields:

$$\beta^2 = \frac{q}{CA_1 \sqrt{\frac{2\Delta p}{\rho}}}$$

with

$C = 0.81$

$A_1 = 1.36 \times 10^{-3}$ ft^2 (1/2" I.D. pipe)

$\Delta p = 518.4$ lb-ft^{-2} (3.6 psid)

$q = 1.645$ slugs-ft^{-3}

Then $\beta^2 = 0.2368$ and $\beta = 0.4866$

Our original choice of a quarter-circle orifice shape has been proven correct because the above value of β is outside the range recommended for the conical orifice.

The final result is the required orifice diameter, D_0, that needs to be machined for this flow measurement as:

$$D_0 = \beta D_1 = 0.4866(0.5) = \underline{0.2433} \text{ inches}$$

12-4 TEMPERATURE MEASUREMENT

The design of automated fluid test systems normally requires the measurement of temperature. Such measurement necessarily is remote-indicating and the candidate techniques for such are listed in Table 12-2.

TABLE 12-2. TEMPERATURE PROBES FOR HYDRAULIC SYSTEMS

Type	Response Time[2] Constant (Sec-Approximate)	Linearity	Cost
Thermocouple	1	Good	Low
Resistance-Temperature Device:			
1 - Platinum	10	Excellent	Highest
2 - Thermistor	2	Fair	Low

1 - The platinum resistance thermometer is so linear, it is used for interpolation between the -182.97°C temperature of liquid oxygen and 630.5°C in the International Practical Temperature Scale (1927).

2 - As normally mounted.

NOTE: The thermistor appears to offer a good match of desirable properties in a small package where the ultimate measurement accuracy is not required.

12-4.1 THE PLATINUM RESISTANCE-TEMPERATURE DEVICE

The platinum resistance-temperature device, being the ultimate in measurement accuracy, is frequently used in hydraulic test systems along with the strain-gauge pressure transducer and the turbine flowmeter (whose accuracy depends on a knowledge of fluid viscosity and, thus, of fluid temperature). Since it utilizes a low-level bridge circuit (self-heating must be kept negligible), an electronic circuit is needed to deliver high-level signals. Typically, over a 100°C range, one of these devices in a bridge configuration can yield linearity of 0.5°C.

12-4.2 THE THERMOCOUPLE

The thermocouple device has been losing ground in recent years to the resistance-temperature devices because of the combination of low-level output and wiring difficulties inherent in maintaining the reference junction with unlike materials. Because of the long history of use and impending obsolescence, no further comment on this type of device appears in this chapter.

12-4.3 THE THERMISTOR

The thermistor is found in increasingly wide use because of its small size, low cost, and rapid response. It also exhibits an order of magnitude greater change in resistance than the platinum resistance-temperature device for a given temperature change. Its resistance change with temperature is far from linear as may be seen from the following typical analytical function:

$$R = R_o \, e^{\beta(1/T - 1/T_o)}$$

where

R = resistance at temperature T

R_o = resistance at temperature T_o

β = constant (characteristic of material) - °K

T, T_0 = + absolute temperature, °K

The reference temperature is generally taken as 298°K (25°C) and the constant β is about 4000.

One may deduce the sensitivity of resistance to temperature by using:

$$\frac{\frac{(dR)}{(dT)}}{R} = -\frac{\beta}{T^2} \quad \% \text{ change} - {}^{o}K^{-1}$$

12-5 ACCELERATION MEASUREMENTS (TRANSLATIONAL AND ROTATIONAL)

The measurement of acceleration falls into the two broad classes: translational acceleration measurement and rotational acceleration measurement.

12-5.1 TRANSLATIONAL ACCELERATION MEASUREMENT

Accelerometers for this purpose are divided into two classes depending upon the frequency content of the acceleration information:

(1) Zero to some cutoff frequency; non-periodic acceleration
(2) Higher frequency, periodic (often sinusoidal) acceleration.

The first of these acceleration domains is characteristic of the condition measured by inertial system accelerometers. These units contain a swinging seismic mass which is either restrained entirely by a stiff spring material or, in the case of the most accurate units, includes a current coil that resists deflection to almost zero. Such accelerometers are not found generally in ground-based automatic test equipment.

Measurement conditions under (2) above are much more common and the piezoelectric accelerometer is by far the most used type in the measurement of shock and vibration.

By the nature of its construction, the piezoelectric accelerometer has no output at zero frequency. Its upper frequency limit is controlled by mechanical resonances within the unit. Accordingly, its transfer function is of the form:

$$\frac{e_o}{\dot{x}_i} = \frac{K_o \tau S}{(\tau S + 1)\left(\frac{S^2}{\omega_n^2} + \frac{2\zeta}{\omega_n} S + 1\right)}$$

where

e_o = output potential (Volts)

x_i = input acceleration ($ft\text{-}sec^{-2}$)

τ = controlled by electrical loading of output (lagtime constant) (Sec)

ω_n = mechanical resonance (Rad-Sec^{-1})

$\zeta \approx$ zero (damping due to crystal only)

(K_o) = transducer gain (ratio of volts output to acceleration input over useful frequency range)

The resulting amplitude response is shown in Figure 12-4.

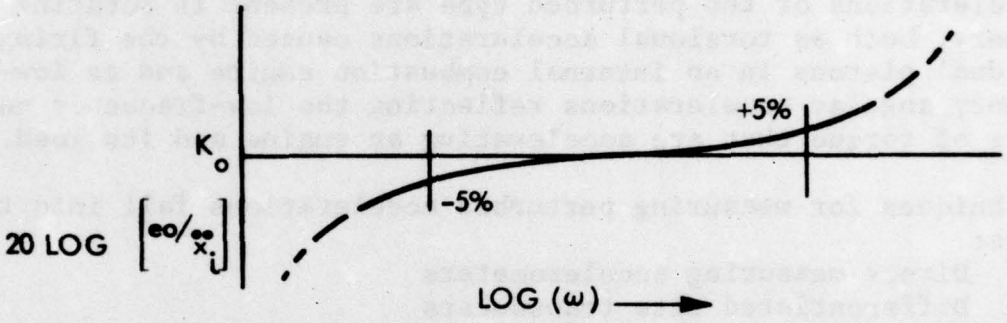


Figure 12-4. Amplitude Response of Piezoelectric Accelerometer.

From the diagram one may deduce the useful frequency range (measurements accurate to $\pm$5 percent) to be:

$$(\tfrac{3}{\tau}) < \omega < 0.2\omega_n$$

With charge-type amplifiers as electrical loads, the low frequency limit is typically 5 Hz. With an upper natural frequency of 30 kHz, the useable upper range limit is about 6 kHz.

12-5.2 ROTATIONAL (ANGULAR) ACCELERATION MEASUREMENT

The measurement of angular acceleration, while not nearly so widely used as the measurement of translational acceleration, is nevertheless expanding in its applications. As in the case of translational acceleration, rotational measurements are found in two categories:

(1) Reversing accelerations:
Characterized by the absence of a superimposed angular velocity so that motion is oscillatory.

(2) Perturbed accelerations:
Consisting of a superimposed angular velocity with oscillatory angular acceleration. If the superimposed angular

velocity is changing, then an additional angular acceleration representing this change is also a part of the measurement.

Accelerations of the reversing type are found in electro-optical systems that are required to stabilize a sight line in the presence of motions of the base. Such measurements are not relevant to ATE use on engines or hydraulic systems.

Accelerations of the perturbed type are present in rotating machinery, both as torsional accelerations caused by the firing of individual pistons in an internal combustion engine and as low-frequency angular accelerations reflecting the low-frequency components of torque that are accelerating an engine and its load.

Techniques for measuring perturbed accelerations fall into two classes:

(1) Direct measuring accelerometers
(2) Differentiated rate transducers

The first of these two is rare indeed. One example is an ac tachometer with its excitation arranged to be dc. The resulting electrical output would then be proportional to the derivative of angular velocity.

Of major importance is measurement by the second type since pickoffs providing angular rate are widely available and signal processing can be applied to generate the desired differentiation:

(1) Differentiated Analog Tachometer Signal - This is the most straightforward approach (at least analytically) and possesses no lower limit on the information frequency (measures steady acceleration) and an upper frequency limit controlled by the tachometer bandwidth or the differentiated signal noise, whichever controls.

(2) Differentiation of a Pulsed Pickoff - It is increasingly common to find pulsed magnetic pickoffs on rotating equipment whose pulse time interval may be used to deduce angular velocity. However, unlike the analog tachometer, the available information frequency band upper limit varies with the base speed because of the limitations caused by sampling. Consequently, if one uses this technique, say on an internal combustion engine over a 10:1 speed range, the pulse frequency must be at least double the desired information frequency (five times is preferred) at the lowest engine speed.

Once the basic information frequency for angular rate is thus established, the further processing to derive angular acceleration is only a matter of measuring two consecutive velocity samples and dividing by the pulse interval (variable with speed). The best

possible accuracy is limited, of course, by the quantization error produced by carrying a finite number of binary bits in the computation.

From the preceding, it is easy to see that the required information frequency for an engine acceleration test is much lower than that required to generate details of acceleration response to the firing of each cylinder. Consequently, this pulse technique may have to be abandoned in the latter case in favor of the analog technique.

12-5.2.1 Angular Acceleration Derived from Angular Displacement

This technique requires two conditions to be satisfied for the measurement of perturbed angular acceleration.

(1) An angular pickoff that has no discontinuities within a full revolution and is, preferably linear in output. (These conditions will never be found simultaneously; e.g., a potentiometer may be linear but it has a cyclic non-linearity; a resolver or synchro has no cyclic discontinuity but it is far from linear.)

(2) A double differention to arrive at acceleration is required and attention must be directed to the selection of the differentiators cut-off frequency to achieve the best balance of signal-to-noise ratio and information bandwidth.

For both of these reasons, the derivation of angular acceleration from angular displacement is not recommended!

12-6 PARTICULATE CONTAMINATION AND MEASUREMENT IN HYDRAULIC SYSTEMS

Although it has been long neglected, it is now realized that particulate contamination can cause premature failure in hydraulic systems even though all relatively large particules have been filtered from the fluid. In fact, damage to hydraulic systems is greatest in that range of particle sizes that corresponds approximately to the clearances provided between moving parts. Accordingly, for typical clearances of 0.0002 to 0.001 inch, corresponding particle sizes of 5 to 25 micron are most critical.

This is the origin of the Armed Forces present efforts to limit particle size in aircraft hydraulic systems to approximately three microns. This is not to say that no particles above this size are tolerable but simply that large numbers are to be excluded.

There exists certain standards for oil quality (Class 0 through 6) in terms of the particle-contamination contained in a 100 ml.

quantity. Such a standard is presented in Table 12-3. It is important to recognize that new fluid, as delivered, is not usually suitable, without additional filtration, for addition in large quantities to a hydraulic system because it contains particulate contamination to a level that may place it in Class 5 or even 6. A graphic comparison of relative particle sizes is presented in Figure 12-5.

TABLE 12-3. STANDARD FOR PARTICULATE CONTAMINATION

Micron Size Range	Particle Contamination Level - By Class						
	Acceptable						Unacceptable
	0	1	2	3	4	5	6
5-10	2,700	4,600	9,700	24,000	32,000	87,000	128,000
10-25	670	1,340	2,680	5,360	10,700	21,400	42,000
25-50	93	210	380	780	1,510	3,130	6,500
50-100	16	28	56	110	225	430	1,000
Over 100	1	3	5	11	21	41	92
Total	3,480	6,181	12,821	30,261	44,456	112,001	177,592

Notes

1. The class of contamination is based upon the total number of particles per 100 milliliters of hydraulic fluid.
2. Class 5 is the maximum acceptable level for hydraulic systems in aircraft and GSE.
3. The Class 5 level of acceptability shall be met at the inspection interval specified for the equipment under test.

12-6.1 PARTICLE MONITORING IN HYDRAULIC SYSTEMS

Hydraulic systems have a peculiar need in some cases to monitor the particulate content in the system fluid as an indication of the general state of health of the unit under test. The hydraulic schematic of Figure 12-6 describes one technique for the sampling offluid as required to measure such contaminants. It consists of:

(1) Sampling solenoids: each energized in turn as required to sample several different points.

(2) Sampling orifice: to restrict the flow for a range of sampling pressures.

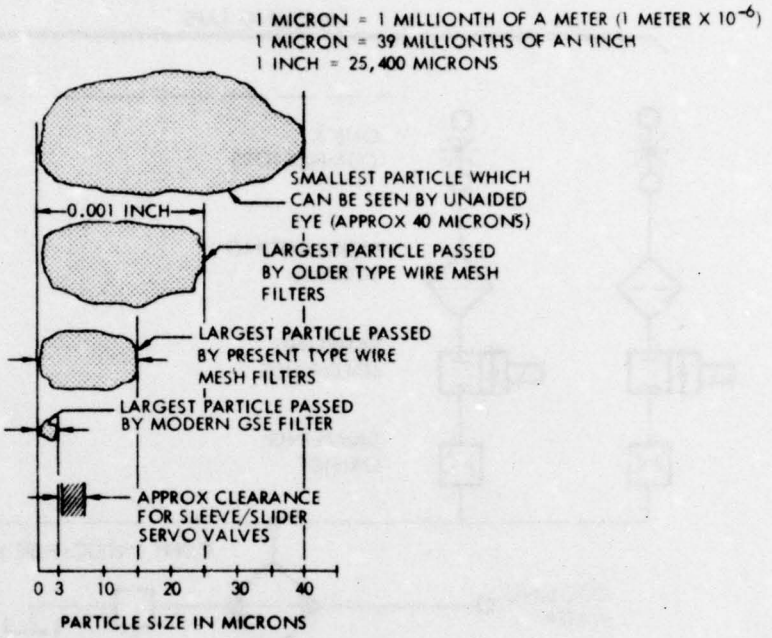


Figure 12-5. Graphic Comparison of Particle Sizes

(3) Filter: to remove particles beyond the size range of the sensor head.

(4) Heat exchanger: to cool (or in some cases heat) the fluid to a standard temperature.

(5) Relief valve: adjusted to divert a prescribed flow through the sensor head.

(6) Sensor head: an electro-optical counter, usually capable of counting particles in the 5 to 150 micron size range.

(7) Control orifice: control sample flow rate

By sharing a common sensor head (and its associated electronics) among several sample points, one may minimize the cost of this most expensive component.

The diagram also shows a water-cooled heat exchanger under the assumption that the fluid temperature will be above ambient. This cooling has a two-fold purpose:

(1) To protect the sensor head against too high a temperature (above about 140°F) that could damage the sensor head.

(2) To provide a constant viscosity fluid that guarantees a constant flow rate through the sensor head (usually adjusted for 100 ml per minute).

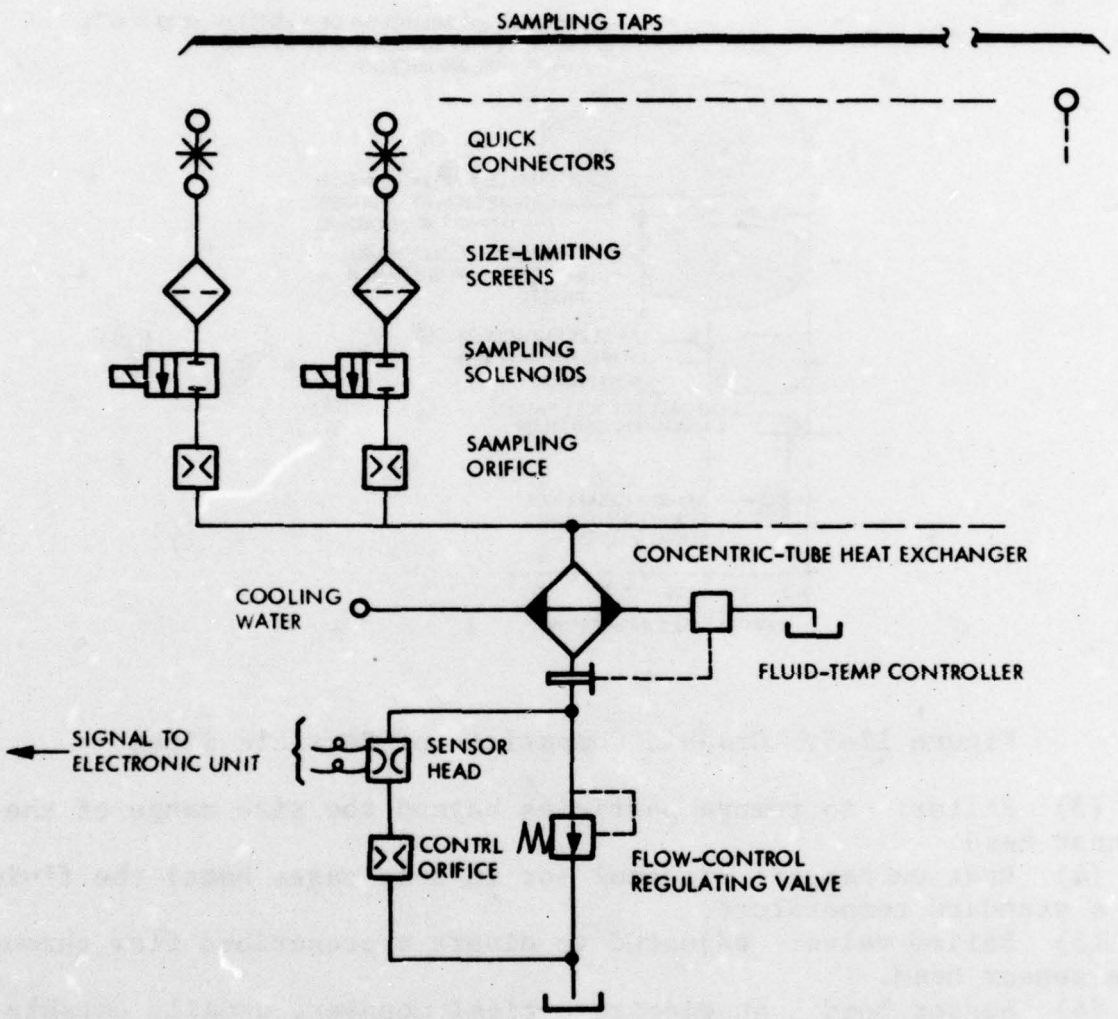


Figure 12-6. Particulate-Monitoring System

By proper selection of sampling solenoids and orifices, one may employ this scheme on hydraulic lines with pressures of at least 20 psid up to any maximum pressure desired. However, the ratio of maximum to minimum pressure accommodated by a single solenoid is limited to about 20:1, which results in a 4.5:1 flow ratio through the flow control relief valve.

The flow control relief valve flow should be arranged to be at least double the sensor head flow as a minimum, and it must be sized such that its pressure regulation characteristics with changing flow will provide a sufficiently constant pressure for

maintaining the required sensor head flow within the desired accuracy (usually ±10 percent).

Finally, the entire hydraulic path must be without excessive voids which might form traps for particles so that one need not wait an unreasonable length of time between samples to assure a flushed system.

REFERENCES

1. Technical Memorandum No. 952, NACA - Standards for Discharge Measurements with Standardized Nozzles and Orifices - Fourth Edition, 1952.

2. Shell Flowmeter Engineering Handbook, Waltham Publishing Company, Delfft, Netherlands.

CHAPTER 13
SAFETY

13-1 GENERAL

Safety precautions designed into equipment are necessary usually as safeguards to lapses of attention. If a mechanic must divert attention from his task to be intent on observing safety precautions, the remainder of his attention might be inadequate for doing his job well; it will certainly take him longer to do the job. Safety measures should, therefore, take into account behavior liabilities such as these.

Design of any equipment must embody features for the protection of personnel from electrical and mechanical hazards and, also, from those dangers that might arise from fire, elevated operating temperatures, toxic fumes, etc. There are various methods of incorporating adequate safeguards for personnel, many of these methods being implicit in routine design procedures. Certain procedures, design practices, and related information are of such importance as to warrant special attention. Personnel are our most valuable commodity. Equipment dangerous to personnel is not maintainable.

13-2 SYSTEM SAFETY

System safety is defined as "the optimum degree of hazard elimination and/or control within the constraints of operational effectiveness, time, and cost attained through the specific application of management, scientific, and engineering principles throughout all phases of a system life cycle".

A System Safety Program (SSP) is a formal approach to the elimination of hazards through engineering design and analysis, management, and supervisory control of conditions and practices, The SSP encompasses the accomplishment of system safety management, research, and engineering tasks, and is an essential element of the operational qualification of the system.

The normal engineering process is illustrated in Figure 13-1. Milestones or checkpoints for system safety within the engineering

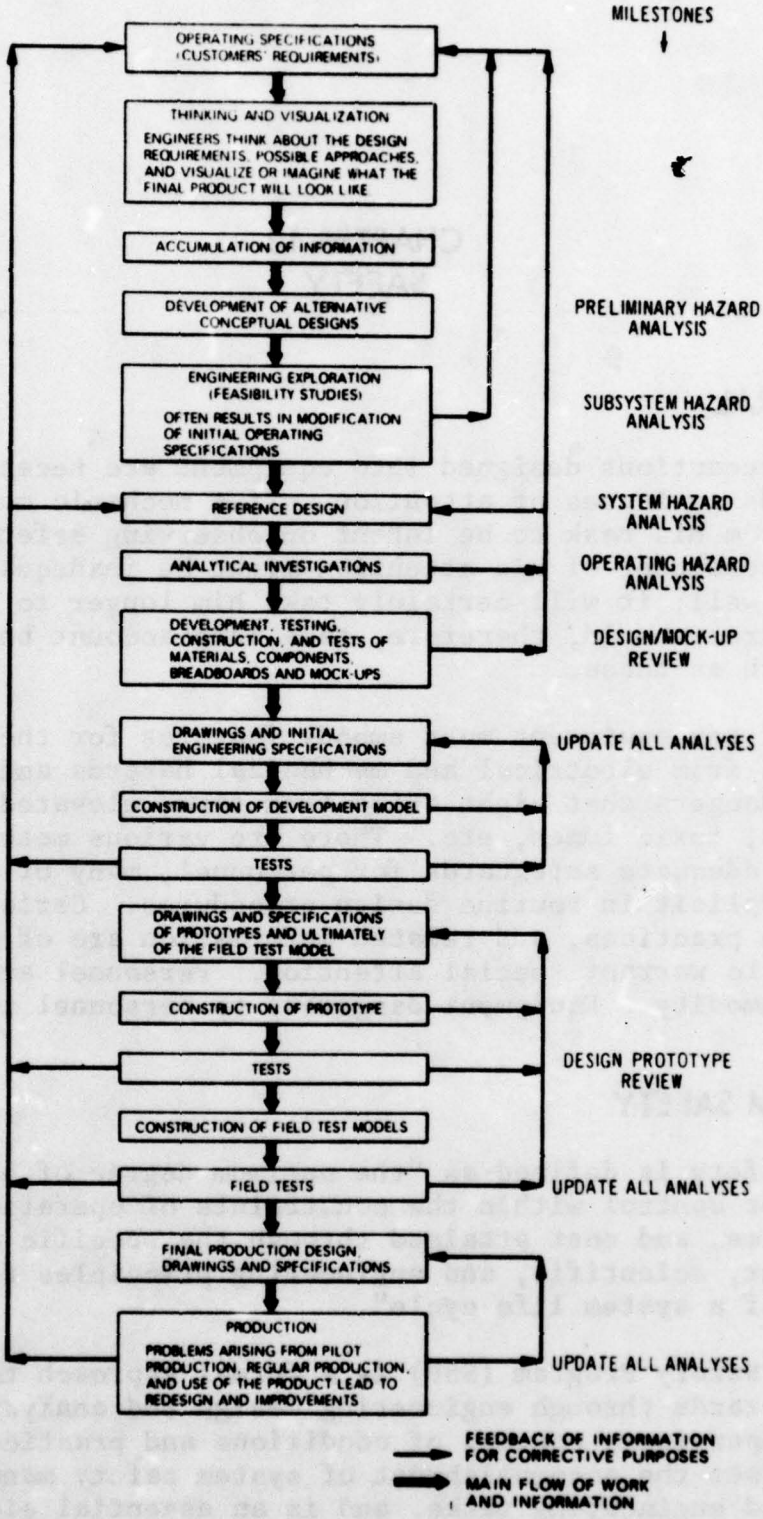


Figure 13-1. System Safety Milestones in Engineering Development

process must be established at the outset of a development program. Typical milestone tasks delineated in MIL-STD-882 (Reference 1) are shown in Figure 13-1 opposite the equivalent tasks in the engineering process. (These milestones are only considered typical and not necessarily complete in number.) The system activity starts early in the preliminary design stage of design and continues throughout the entire process. The safety system process described subsequently is applied in an iterative manner as the program progresses.

System safety requirements throughout the entire life cycle are beyond the scope of this handbook. Only the periods from contract definition through qualification are included.

13-2.1 OBJECTIVES

The ultimate objective of a System Safety Program is to maintain the highest level of operational mission effectiveness through the conservation of human and materiel resources by the early identification, evaluation, and correction of system hazards. This objective is obtained by insuring that:

(1) Safe features consistent with mission requirements are designed into the system from the beginning of the design process.

(2) Hazards associated with each system, each subsystem, and allied equipment are identified, evaluated and eliminated or controlled to an acceptable level.

(3) Control is established over hazards that cannot be eliminated by design selection to protect personnel, equipment, and property.

(4) Minimum risk is involved in the acceptance and use of new materials and new production and testing techniques.

(5) Retrofit actions required to correct hazardous conditions are minimized through the timely application of safety criteria from the preliminary design through qualification phases of a system.

(6) Retrofit actions taken to improve performance, maintainability, reliability, or other functions are considered from the standpoint of safety with respect to interfacing subsystems or allied equipment.

(7) The historical safety data generated by similar system programs and operational experience are used to preclude the incorporation of previously identified hazards into the new system.

13-2.2 SYSTEM SAFETY PROCESS

The system safety process is shown graphically in Figure 13-2 and described subsequently. This process shows a logical approach

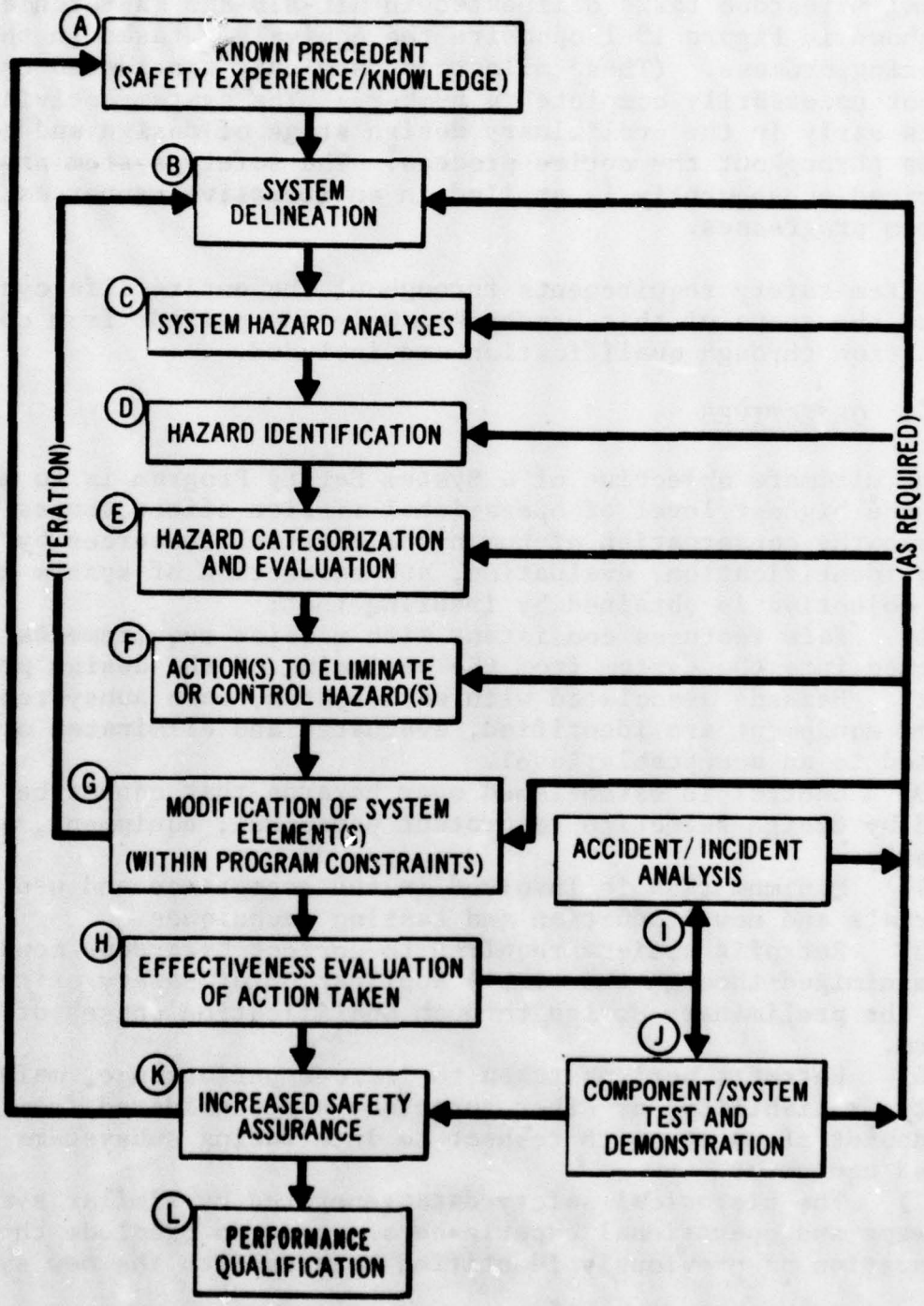


Figure 13-2. System Safety Process

to attaining the system safety objectives specified in paragraph 13-2.1. The process is repeated as necessary in an iterative fashion at every level of complexity in the design of a system until the requisite assurance of the system hazard level is attained. The SSP Plan shall reflect how the contractor plans to apply this process in the conduct of his System Safety Program.

13-2.2.1 Known Precedent (Block A, Figure 13-2)

From the beginning, a System Safety Program must be based on the experience and knowledge gained from previous operations in correcting design features which have resulted in the accidental loss or damage to materiel or injuries or death to personnel. Those design features which have not shown unacceptable hazards also are identified. It is essential that the designers of future systems benefit from all previous experience which affects safe operation.

13-2.2.2 System Delineation (Block B)

The boundaries of the system under consideration and its constituent elements are defined clearly as early as possible and revised as required during the system life cycle. Such delineation establishes the limits for succeeding steps in the process and reduces complex systems to manageable parts. Any entity can be labeled a "system" provided it is accurately defined.

13-2.2.3 System Hazard Analyses (Block C)

The heart of the system safety process is the analysis of a system and its elements in a comprehensive and methodical manner. Beginning with preliminary hazard analyses of design concepts and continuing through an integrated hazard analysis of the complete system, this analytical process distinguishes system safety from other separate, but closely interfacing, disciplines. The contractor will select the methodology and techniques for hazard analysis best suited for the particular system element under consideration and for the applicable level of detail in design.

13-2.2.4 Hazard Identification (Block D)

Using the systematic hazard analyses, the designer/engineer identifies those features of a system which potentially may cause damage, loss, or injury. Such identification assists the designer in his initial efforts by calling attention to undesirable features which either can be eliminated or controlled efficiently early in

the design process. As design proceeds additional hazards are identified throughout the system safety process.

13-2.2.5 Hazard Categorization and Evaluation (Block E)

It is impractical to eliminate all hazards identified in a system. The appropriate action to be taken as a result of hazard identification depends on the nature and degree of severity of the hazard. Categorization of hazards according to criteria specified by the procuring activity serves to guide corrective action based upon degree of severity. Evaluation of identified hazards requires relating a hazard to its impact on mission effectiveness, system performance, and program success. This categorization and evaluation are essential parts of the decision-making process as to appropriate corrective action.

13-2.2.6 Action(s) to Eliminate or Control Hazard(s) (Block F)

The system safety process produces no useful result until some action is taken to eliminate or control identified hazards. The effect of alternative courses or action in the design process and trade studies to eliminate or control identified hazards should be considered. Thus, management is presented with a tool by which decisions can be made in the light of other program constraints.

13-2.2.7 Modification of System Element(s) (Block G)

Any action taken in Block F necessarily will result in the modification of some element or elements of the system. As a result, the delineation of the system (Block B) must be revised accordingly. The system safety process then is repeated as required until such time as no unacceptable additional hazards are generated by the system modification. This step insures that a new hazard is not inadvertently introduced into the system while another hazard is eliminated.

13-2.2.8 Effectiveness Evaluation of Action Taken (Block H)

Actions taken to correct hazards as a result of the system safety process are evaluated for their effectiveness in accomplishing the system safety objective. A satisfactory evaluation results in increased assurance in the level of safety of the system (Block K).

13-2.2.9 Accident/Incident Analysis (Block I)

The occurrence of an accident or incident, of course, leads to an unsatisfactory evaluation. The analysis of such accident or incident experience should reveal any deficiencies in the conduct of the system safety program and direct corrective action to the appropriate step in the process.

13-2.2.10 Component/System Test and Demonstration (Block J)

Analytical techniques alone will not be sufficient to adequately identify system hazards. This inadequacy is determined in Block H. Tests and demonstrations normally conducted as a part of a development program are planned and conducted to reveal and correct such inadequacies. In addition, these tests and demonstrations serve to verify the results of the system safety process and contribute to the assurance desired. Should system testing reveal additional problems, corrective action is applied at the appropriate step in the process.

13-2.2.11 Increased Safety Assurance (Block K)

The assurance that the objectives of system safety are being met is cumulatively increased as the program progresses and contributes increased knowledge for subsequent cycles of the process (Block A).

13-2.2.12 Performance Qualification (Block L)

Ultimately, the system safety process results in data and information which serve as an essential element of performance qualification. Methods and procedures to be followed are prescribed in the Qualification Specification.

13-2.3 ANALYTICAL METHODOLOGY

Hazard analysis is the heart of the system safety process. The primary emphasis in analysis is on inductive thought. Deductive reasoning also is employed but to a lesser degree.

The ultimate purpose of hazard analysis is to aid management in reaching the determination that the objectives discussed in paragraph 13-2.1 have been achieved within the constraints of the particular development program. In addition,these analyses form a baseline which can be evaluated objectively by someone other than a system safety analyst to measure the effective influence of subsequent design changes.

There are several types of widely used analyses for system safety. Selection of analytical methodology or techniques to be used in a given program is the responsibility of the contractor and depends upon the level of detail required by program phases, requirements for quantitative or qualitative results, and the particular capabilities developed by the contractor.

Two of the most useful safety analysis techniques are Failure Modes and Effects Analysis (FMEA - Reference 6) and Fault Tree Analysis (FTA - Reference 7). An FMEA is a procedure used to define the effects on system operation of failure modes. An FTA can be defined as a systematic deductive technique for searching out possible causes of system failure.

Some of the relative advantages of Fault Tree and Reliability Analysis are as follows:

(1) The Fault Tree is the optimum technique for multiple failures, whereas Reliability Analysis is the optimum technique for single failures.

(2) The Fault Tree does not require analysis of failures which have no effect, whereas Reliability Analysis provides documentation to insure that every potential single failure has been examined.

(3) The Fault Tree is event oriented. It easily identifies higher level events or events subsequent to failure. The Reliability Analysis is hardware oriented. It easily identifies results of failure of any component, subsystem or system.

(4) The Fault Tree identifies all external influences which contribute to loss such as human errors, environment and test procedures, whereas Reliability Analysis does not require investigation of as many external influences, and the associated data is not required.

(5) The Fault Tree has a restricted scope with analysis in depth while Reliability Analysis has a broader scope with restricted depth of analysis.

Each method is ideally suited and optimum for its primary purpose -The Reliability Analysis for functional or "mission" analysis; and the Fault Tree for "rare event" analysis such as "loss of life" (safety) or "physical destruction of equipment" (system safety). The two methods complement each other nicely. As the single failure points identified earlier by Reliability Analysis are being worked, Fault Tree analysis identifies the catastrophic multiple failures which should be the next order of business. The Reliability Analysis covers hardware and the Fault Tree covers events to give a capability of answering a broader range of questions. The combinations of the two techniques provide an integrated

analysis program which is more program effective than either could be alone.

13-2.4 KNOWLEDGE OF HAZARDS

The system safety analyst must have a thorough knowledge of not only the engineering sciences but also of hazardous conditions.

For example, major equipment configurations have inherent safety implications. The trade-offs utilized to reach a decision regarding these configurations must include system safety considerations. In addition, hazards are more likely to be present at interfaces between subsystems than within a single subsystem.

The system safety analyst also must be aware of those conditions which have been proven by past experience to be hazardous. And the consideration of hazards must not be limited to those conditions involving only hardware. The interactions of the equipment with personnel who operate and maintain it, and between personnel and the environment in which the equipment is utilized, provide potentially hazardous conditions which must be considered during design.

13-2.5 CLASSIFICATION OF HAZARDS

Since it is impossible to eliminate and/or control all possible hazards, they are usually ranked in degree of severity (i.e., consequence in operation of the equipment). Four hazard levels ranging from negligible to catastrophic are defined and established in MIL-STD-882. However, this is not the only acceptable way to classify hazards. Besides the consequence of the hazards, the probability and resources required to eliminate and/or control them must be considered before the procuring activity can authorize expenditure of resources to resolve the hazards. The contractor shall develop a procedure to categorize hazards which is compatible with the program requirements.

13-2.6 RESOLUTION OF HAZARDS

MIL-STD-882 discusses the methods of resolving hazards. The first, and most desirable method, is to eliminate an identified hazard by selection of a design in which the hazard does not appear. If elimination of a hazard is impossible or uneconomical, the next step is to make the system tolerant of the hazard.

Three ways of making a design tolerant of identified hazards are stipulated in MIL-STD-882 in a descending order of desirability. The first alternative is to reduce the significance of a hazard through the use of appropriate safety devices. Ideally, such devices should not require human intervention but should operate automatically if the specified hazardous condition arises.

The next choice is to place warning devices in the system to make known to the crew the existence of a hazardous condition. These devices would require human intervention to respond to the warning produced. Audio or visual indicators are commonly used in this respect, but there is a limit on the number of such devices that can be effectively employed in a system design. Such features must be coordinated closely with the human factors engineering function.

The final, and least desirable choice is to prepare, disseminate, and enforce special operating procedures regarding an identified hazardous condition. However, these procedures are a weak link in the achievement of system safety because of the inability to verify communication of the procedure to the person who must operate in accordance with such procedures.

13-2.6.1 Substantiation of Hazard Resolution

Once each possible hazard has been analyzed for its significance and the resolution of the hazard is determined, there is need for assurance that proper corrective action has been taken. This can be accomplished by inspection, additional analyses, and design reviews.

A particular type of design review which is effective for system safety is the mock-up review. The mock-up also can become an excellent method of identifying additional potential hazards. Additionally, the mock-up brings the subsystems together at an early stage, before interface problems become too expensive to change.

13-3 HAZARDS

13-3.1 MECHANICAL

To minimize the possibility of physical injury, all edges and corners should be rounded to maximum practical radii. This is especially important for front-side edges and door corners. Thin edges should be avoided and construction should be such that the unit can be carried without danger of cutting the hands on the edges.

To prevent hazardous protrusions from surfaces, flathead screws should be used wherever sufficient thickness is available; otherwise panhead screws should be used. All exposed surfaces should be machined smooth, covered or coated to prevent the possibility of skin abrasion. Small projections, in areas where rapid movement can cause injury, should not be left uncovered. Recessed mountings are recommended for small projecting parts such as toggle switches and small knobs located on front panels.

Shields and guards should be made part of the equipment to prevent personnel from accidentally contacting rotating or oscillating parts such as gears, couplings, levers, cams, latches, or heavy solenoid equipment. Moving parts should be enclosed or shielded by guards. Where such protection is not possible, adequate warning signs should be provided. High temperature parts should be guarded or so located that contact will not occur during normal operation. Guards should not prevent the inspection of mechanisms, the failure of which will cause a hazardous condition. Guards should also be designed to permit inspection without removal whenever possible.

Ventilation should be provided so that no part or material attains a temperature which will tend to damage or appreciably reduce its normal useful life. No exposed parts of the equipment should, under any condition of operation, attain temperatures hazardous to personnel. Forced air is permitted through replaceable, renewable, or cleanable dust filters. Air exhaust openings should not be located on front panels or other locations which expose personnel to direct drafts.

Some housings, cabinets, and covers require perforations to provide air circulation. In these, the area of a perforation should be limited to that of a 0.5-inch square or round hole. High-voltage, rotating, or oscillating components within should be set back from the perforated surface far enough to prevent accidental contact by personnel. If this cannot be done, the size of the perforations should be reduced.

Where access to rotating or oscillating parts is required for maintenance, it might be desirable to equip the protective covers or housings with safety switches or interlocks. The cover or housing should bear a warning sign such as:

CAUTION KEEP CLEAR OF ROTATING PARTS

Electronic chassis in their normal installed positions should be securely enclosed. Stops should be provided on chassis slides to prevent pulling the chassis too far out and dropping it. Suitable handles or similar provisions should be furnished for removing chassis from enclosures. Bails or other suitable means should be provided to protect parts when the chassis is removed and inverted for maintenance, and to protect the hands as the chassis is placed on the bench.

13-3.2 FIRE

All reasonable precautions should be taken to minimize fire hazards. In particular, any capacitors, inductors, or motors that are possible fire hazards should be enclosed by a noncombustible material having minimum openings. Because many equipments are installed in confined spaces, materials that can produce toxic fumes should not be used. Finished equipment should be carefully checked for verification of protective features in the design. Avoid materials that under the adverse operating conditions will liberate gases or liquids that are, or may combine with the atmosphere to become, combustible mixtures. Design equipment that will not emit any flammable vapors during storage or operation. Provide suitable warnings or automatic cutoffs to operate if such vapors are emitted during operation. Equipment should not produce undesirable or dangerous smoke and fumes.

Where known fire hazards exist, or may be created by the equipment itself, provide hand-operated, portable fire extinguishers. Locate extinguishers so they are easily and immediately accessible, and provide those suitable for the type of fire most likely to occur in the area. The three general classes of fires are as follows:

Class A. Fires occurring in ordinary combustible materials such as wood, paper, and rags, which can be quenched with water or solutions containing water.

Class B. Fires occurring in flammable liquids such as gasoline and other fuels, solvents, greases, and similar substances, which can be smothered by diluting, eliminating air, or blanketing.

Class C. Fire occurring in electrical equipment such as motors, transformers, and switches, which must be extinguished by a nonconductor of electricity.

13-3.3 TOXIC FUMES

All reasonable precautions should also be taken to eliminate the hazards from toxic fumes. The exhausts from internal combustion engines for example, contain numerous hazardous substances.

From the standpoint of practical health hazard control, however, the most important constituents are carbon monoxide from gasoline engines, and aldehydes and nitrogen oxides from diesel engines. Figure 13-3 illustrates the effects of carbon monoxide on human beings. Table 13-1 gives a brief list of common toxic agents and their maximum allowable concentrations.

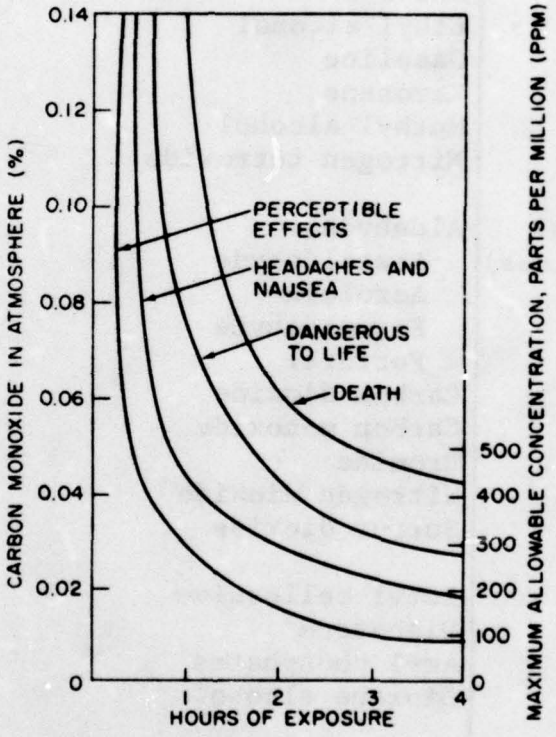


Figure 13-3. Effects of Carbon Monoxide for a Given Time on Human Beings

Caution should be used in the interpretation of these charts, because toxicology is a rather complex science and does not lend itself simply to the summary given by the charts. In fact, the information can be misleading and dangerous if the user tends to apply numbers based on one kind of exposure to quite different exposure conditions. The design engineer should remember that toxicology involves life and death, and that a profession toxicologist should be consulted for data pertaining to specific exposure conditions.

TABLE 13-1. COMMON SOURCES AND MAXIMUM ALLOWABLE CONCENTRATIONS OF SOME TOXIC AGENTS

Common Source	Toxic Agent	Maximum Allowable Concentration (ppm)
Fuels and propellants	Ammonia	100
	Aniline	5
	Ethyl alcohol	1000
	Gasoline	250
	Kerosene	500
	Methyl alcohol	200
	Nitrogen tetroxide	5
Engine exhausts (including rocket engines)	Aldehydes:	
	Acetaldehyde	200
	Acrolein	0.5
	Formaldehyde	5
	Furfural	5
	Carbon dioxide	5000
	Carbon monoxide	100
	Bromine	1
	Nitrogen dioxide	5
	Sulfur dioxide	5
Hydraulic fluids	Butyl cellosolve	50
	Diacetone	50
	Aryl phosphates	0.06
	Dioxane alcohol	100
Fire extinguishants	Carbon dioxide	5000
	Carbon tetrachloride	25
	Chlorobromethane	400
	Methyl bromide	20
Oil sprays and fumes	Aldehydes: (see above)	
Refrigerants	Carbon dioxide	5000
	Freon	1000
	Methyl bromide	20
	Sulfur dioxide	5
Smoke	Phosgene (see also engine exhausts)	1

13-3.4 INSTABILITY

Design all equipment to provide maximum stability. Give particular consideration to maintenance stands, tables, benches, platforms, and ladders. Use non-skid metallic materials, expanded metal flooring, or abrasive coating on walkways, catwalks, and all surfaces used for climbing. On steps and ladders, use non-skid treads or cover them with abrasive material. Design ladders and steps so they can be deiced with hot water or steam. Place hand grips on platforms, walkways, stairs, and around floor openings. Ordinarily these hand grips should be fixed; if not, they may be folding or telescoping, normally concealed, or flush with the surface. Such hand grips should remain securely folded when not in use, and tools should not be required to move them from the folded position.

To prevent accidental or inadvertent collapse or lowering of elevating stands and platforms, incorporate self-locking, foolproof devices in the equipment. Where stands have high centers of gravity and can be overturned by winds, use anchors or outriggers. Also, to prevent over-loading, indicate the capacity in pounds on stands, hoists, lifts, jacks, and similar weightbearing equipment.

Design equipment for maximum safety and stability when it is moved up an incline, such as a cargo ramp, or lifted by cranes for shipping. Provide a suitable marking indicating the location of the center of gravity (Figure 13-4) and jacking points. When moving up an incline, the weight distribution on the vehicle wheels may change-more weight will be taken by the rear wheels-and this will possibly exceed the allowable ramp loading on heavier types of equipment. Also, the closer the center of gravity acts to the rear contact point, the greater tendency the vehicle will have to overturn during sudden acceleration forward or hard braking while rolling backward.

13-3.5 NUCLEAR RADIATION

Hazards to personnel and equipment resulting from nuclear radiation and detonation should be investigated by personnel trained in investigating and controlling such hazards.

13-3.6 HYDRAULICS

The exercise of certain precautions in the storage and handling of hydraulic fluids is vital for the safety of personnel and for the protection of the fluid. The introduction of contaminants into

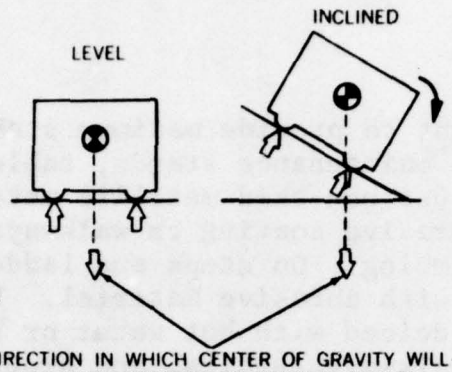


Figure 13-4. Effects of Incline on Center-of-Gravity Location of Equipment

the hydraulic fluid and contact with incompatible materials are both to be avoided. Personal hazards from explosion, fire, skin poisoning, ingestive poisoning, and vapor inhalation are of even more concern. Anyone who stores and handles hydraulic fluids should know well the hazards they face and follow all recommended safety precautions.

13-3.6.1 Health Hazards

Skin poisoning, ingestive poisoning, and exposure to vapors and sprays of hydraulic fluids are common threats to hydraulic fluid handlers. Other dangers are due to the explosive or highly flammable nature of some liquids. Most hydraulic fluids, however, do not pose a serious health hazard. For specific information on the hazardous nature of a particular fluid, the fluid manufacturer should be consulted.

13-3.6.2 Precautions Against Poisoning

Skin poisoning or irritation caused by repeated handling of a hydraulic fluid, and ingestive poisoning caused by accidental swallowing are two hazards that can be easily guarded against. The swallowing of a hydraulic fluid is very rare. Nonetheless, poisonous hydraulic fluids should be clearly marked as such and an antidote or other first aid procedure should be known from the manufacturer's data or from cautionary information on the fluid container. For all hydraulic fluids, the avoidance of extended contact with the skin is recommended. Although most hydraulic fluids, including synthetics, are not harmful to bare skin, prolonged contact should be avoided because many of the ingredients and additives may tend to dry out the skin. However, the effect is usually not long lasting if the exposure is not prolonged.

13-3.6.3 Precautions Against Dangerous Vapors and Sprays

Vapors and mists from many hydraulic fluids are generally irritating and cause coughing or sneezing. For these reasons prolonged inhalation of hydraulic fluid vapors or sprays is to be avoided. Even when the effects of short exposures are known to be nontoxic, indirect damage to the respiratory system could occur because of frequent or repeated irritations. Vapors from hydraulic fluids are most irritating when the fluid is at high temperatures, as the fluid may decompose and give off toxic vapors. Then, and at all times, the general rule is to avoid vapors from hydraulic fluids by working in well ventilated areas or by wearing protective masks.

13-3.6.4 Danger of Explosion and Fire

The danger due to explosion of hydraulic fluids is possible during storage, handling, or use in a hydraulic system. The "explosive limits" of a substance are the lowest and highest concentrations of the vapors of the substance in the atmosphere which will form a flammable mixture. Hydraulic fluids should not be stored where the temperature may become high enough to ignite the fluid. A common precaution that should be taken is to store the hydraulic fluid in an area removed from all possible sources of ignition and from areas where personnel or equipment would be endangered should the stored liquids be accidentally ignited.

Fire and explosion precautions are even more important in direct handling of hydraulic fluids. Pouring or draining of fluids near sources of ignition (such as direct flames or hot surfaces) is inviting disaster. Even fire-resistant fluids can ignite and continue to support flame if conditions are favorable.

Serious fire hazards can occur when a liquid is in use in a hydraulic system. Because of the high pressure in components of the system, flammable hydraulic fluids in the event of a system failure (broken hose, line, coupling)-can spray system components and surroundings that may be hot enough to cause ignition. If the liquid is conducting, the spray can also cause short circuits in electrical systems which, in turn, can cause ignition. Precautions against this sort of fire hazard are the responsibility of the system designer. If possible, the probable points of system failure should be situated so that, should a leak occur, the hydraulic spray will not be exposed to potential ignition sources.

13-3.6.5 Other Precautions

Additional areas requiring precautions pertain to the relationship of hydraulic fluids with other materials.

All hydraulic fluids are incompatible with some materials. The designer takes this into account when choosing system components and a hydraulic fluid for the system. On occasion, however, users of a hydraulic system may desire to use a different hydraulic fluid. In changing to a different fluid, one should always investigate the safety of the change thoroughly. If the new fluid is incompatible with any system component, eventual system malfunction is probable. The fluid manufacturer can supply data on compatibility of his fluid with commonly used system materials.

13-3.6.6 Storage and Handling

The function of hydraulic fluid containers is simply to contain the fluid during transport and storage. The container must be strong and tight enough to assure protection of its contents, and it must preserve the original cleanliness of the fluid. Characteristics important to the design and selection of containers for a specific hydraulic fluid include the container materials, dimensions, and storage conditions to which the container will be subjected. Also of importance are standards for proper labeling and guidelines for the purchasing and ordering of containers.

Industrial and military requirements for materials for hydraulic fluids containers vary, but the usual materials are steel or aluminum. In general, military hydraulic fluid specifications for containers for one gallon or less require that they be packaged in metal cans, 28 gage or lighter, conforming to Federal Specification PPP-C-96D (Reference 2). Heavier gage steel is used for containers of 5- and 55-gallon capacities. For instance, 55-gallon drums must comply with Federal Specification PPP-D-711E (Reference 3) and range from 12 to 18 gage; 5-gallon containers must comply with Federal Specification PPP-P-704C (Reference 4) and range from 24 to 26 gage.

Exterior coatings for military purposes usually conform to Federal Specification TT-E-515 (Reference 5) for quick-drying enamel. Containers of one gallon or less are generally painted red, while larger containers are painted olive drab. Exterior coatings for commercial use depend on the manufacturer's preference and frequently incorporate a color code to distinguish the contents.

Interior coatings or liners are common for hydraulic fluid containers made for commercial use, especially the 55-gallon drums. For Military Specification fluids, however, interior coatings or liners generally are not required. When interior coating or liners are used, they must be of a material that will not react with the hydraulic fluid.

13-3.6.7 Hydraulic/Pneumatic Safety Design Guidelines

When designing a hydraulic system or component, the designer must consider possible installation errors and the effects of such errors on the system or component. The effects of failures in equipment located adjacent to hydraulic system components should be reviewed. The following items should be considered:

(1) Steel hydraulic tubing must be used in power plant compartments. The firewall or flame-tight diaphragm must be considered the dividing point for using other than steel tubing.

(2) Where two or more lines are attached to a hydraulic component, the fittings should be sufficiently different, where practicable, to prevent incorrect connection to the component.

(3) Hydraulic lines should be located as remotely as practicable from exhaust stacks and manifolds and from electrical, radio, oxygen and equipment lines. In all cases, hydraulic lines should be located below the aforementioned to prevent fire from line leakage.

(4) Where small-diameter tubing is used (less than 1/4-inch OD), particular care should be exercised to insure that the tubing will be installed, supported and protected properly.

(5) Drain or vent lines from the pump, reservior, or other hydraulic components should be incapable of being connected to other fluid systems such that mixture of fluid can occur in the components being vented or drained.

(6) Emergency air lines should be separated as far as practicable from the normal hydraulic lines connected to a particular component or subsystem.

(7) The possibility of interconnection of supply and return portions of the system should be precluded.

(8) Incorporation of components and lines in areas that are subject to being walked on by servicing and maintenance personnel should be avoided.

(9) Cushion clamps (Teflon preferred) should be used for all lines. Supports should be placed as close as practicable to bends (but not in bends) to minimize overhang of the tube. In areas of high vibration, the line support spacing should be reduced.

(10) Provision should be made for at least a 20 percent elongation in order to minimize line breakage.

Many problems can be averted or alleviated by considering possible component failure modes and causes in the preliminary design phase and incorporating simple precautionary measures. The following items should be considered:

(1) Components should be designed so they cannot be installed improperly. A critical actuator should be designed so that it is impossible to reverse the cylinder or cross lines during installation of check valves; these valves, if installed backwards, can cause loss of an entire system.

(2) A two-pump system should have a nonbypasstype, sufficiently large, filter in the case drain line of each pump.

(3) Flexible hose may be used in the system for:

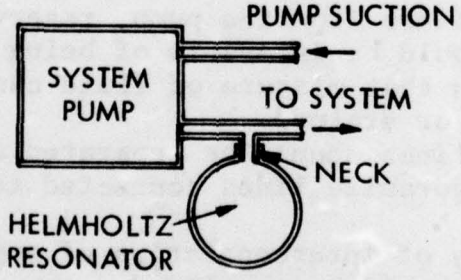
(a) Insulation against noise and shock

(b) Plumbing in close quarters

(c) Component connections that must move during component operation.

Hoses should be used to connect pumps to the system. The designer should insure that hoses are not flexed in more than one plane of motion and are adequately protected against chafing, also that support clamps are not spaced too far apart (24 inches or less). Slack of 5 to 8 percent of the total length between components should be allowed.

(4) System pressure pulsations resulting from pump ripple being intensified by system resonance can be attenuated by providing adequate elasticity to the system at the pump outlet port. Use of a Helmholtz resonator design, shown in Figure 13-5, should be considered. Short, dead-ended lines near the pump should be avoided.



THE FLUID IN THE NECK ACTS AS A MASS AND THE SPHERICAL VOLUME AS A SPRING IF THE FREQUENCY OF THE RESONATOR IS TUNED TO THE INCIDENT WAVE COMING FROM THE PUMP. THERE IS A VIBRATION IN AND OUT OF THE LARGE VOLUME, BUT NO EXCESS PRESSURE AMPLITUDE.

Figure 13-5. Helmholtz Resonator

(5) Pump cavitation will occur if the reservoir pressurization is not sufficient to accelerate the column of oil in the suction line to a flow rate compatible with the pump displacement and within the response time of the pump compensator. This response demand condition is more likely to be a critical design condition than is steady-state flow.

(6) Filters incorporated in valves-e.g., restrictors and T-valves-should be larger in micron rating than system filters to avoid clogging. The normal size is 50 microns. Such component filters should be pencil-type design, rather than flat disk-type, for higher dirt capacity at lower pressure drop. They should be retained adequately, not pressed in, to avoid blow-out due to back pressure surges. In T-valves, central filtration should be used to avoid differential flows as filter pressure drop increases.

(7) Lubrication should be provided for all critical joints. Dry lube should be compatible with hydraulic fluid. Graphite-loaded grease in high-temperature applications can result in the grease drying up and leaving a hard graphite collection that can cause interference and contamination problems. Long lubrication paths sometimes result in frozen grease and blocked fittings.

(8) Reservoirs should incorporate air bleed vents that are high enough to optimize their capability to bleed the system. The suction outlet should be placed low to reduce suction line loss. The overboard relief flow capacity should be sufficient to prevent reservoir damage when such relief capability is needed.

(9) Motors, pumps, or other components operating with different fluids or lubricants should incorporate adequate sealing provisions in separation members. If two seals are used, adequate venting of the common chamber between the seals should be provided for fluid drainage, thereby avoiding pressure buildup, interflow of fluids, and/or noncompatible seal deterioration.

(10) Components incorporating face seals should have adequate mounting bolts and lug strength to prevent flexing due to pressure surges. Flexing can cause seal or backup ring extrusion. Face seals can be avoided entirely through the use of transfer tubes.

(11) In designing poppet valves, aluminum seats should not be used. Insufficient seat area, combined with high seating forces, can cause Brinelling of the seat. Excessive leakage and/or sticking of valves can result.

(12) Snap rings should not be used in components where, under loaded conditions, snap ring failure can cause slippage of internal parts or cause a component to come apart completely.

(13) Cold flow materials used for poppet seats should be supported sufficiently to prevent excessive creep. Malfunctions due to change in poppet travel and/or leakage can result if this is not done.

The combinations of the two techniques provide an integrated

Military Specifications require, as a minimum, that the hydraulic system incorporate a pressure indicator common to each pump in a system and that each system incorporate a low pressure indication. The designer should consider the actions that may be taken if an indication of an abnormal condition occurs. This is important in that erroneous indications due to an instrumentation failure may cause unnecessary actions to be taken. Such an evaluation by the designer may result in consideration of redundant or alternate means of indicating critical system parameters.

It is a good design practice to include fuses and snubbers at the upstream ends of the lines leading to pressure sensors or transmitters to protect the devices from surge pressures. Rate-or quantity-measuring fuses may be incorporated to shut off fluid loss in the event of line rupture. Snubbers act to damp forces resulting from pressure surges in dead-ended lines. A possible alternative is to install pressure sensors into fittings in the system line instead of in an appendant line. If this is not possible, the snubber and fuse should be installed at the teeoff point.

Care should be taken in the design of pressure transmitters with Bourdon tubes and rack and pinion-type gearing. These are susceptible to bearing wear caused by vibration or pressure fluctuations. Helical sensing elements are preferred. Sensing elements may be encased in a compatible fluid to provide vibration and shock protection. A blowout plug should be incorporated into the case to prevent pressure buildup and/or rupture in the event of a leak in the sensing element.

13-3.6.8 Over-Pressure Relief for Hydraulic Systems

In the design of hydraulic systems, the unexpected appearance of excess pressure is the most common hazard to the safety of personnel that is encountered. The available techniques for preventing dangerous over-pressure, in the order of use-rate, are:

(1) Relief valves
(2) Rupture discs

The relief valve is the device most commonly employed in systems because:

(1) It is usually adjustable for set pressure
(2) It is automatically resettable.

It is, however, deficient in reliability and speed-of-response compared to the rupture disc which, however, must be replaced

following each and every over-pressure condition. Nevertheless, where the ultimate in reliability is required and infrequent over-pressure conditions exist, the burst disc is the preferred device, not only for the safety of personnel, but also for the protection of equipment that may well be damaged by a sharp over-pressure spike.

13-3.6.9 Over-Temperature Automatic Protection

A less frequently but no less dangerous condition to that of over-pressure is the over-temperature condition. The appearance of this condition, however, takes place in a time scale normally 100 to 1000 times slower than that of over-pressure so there is no particular difficulty in sensing and responding to the condition in time to prevent dangerous over-temperature situations. If allowed to persist, these over-temperatures can cause rupture in bases operating at normal working pressure and subsequent fire (if the fluid is not one of the special fire-resistant varieties).

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PART V

CONSIDERATIONS APPLICABLE TO SPECIFIC TYPES OF MATERIAL

CHAPTER 14
GASOLINE AND DIESEL INTERNAL COMBUSTION ENGINES

14-1 GENERAL

Maintenance concepts for gasoline and diesel powered internal combustion engines will be discussed in this chapter. These engines have conventionally been designed for mass production, with primary concern for cost and produceability. Total life cycle costs often show that maintenance and repair are very significant factors compared to the original equipment cost. Because the addition of test points or imbedded measurement transducers must add to the original cost of the engine, it is unlikely that such devices will be incorporated into the engine design unless specifically imposed as part of the procurement specification. The following paragraphs highlight performance functions which must be tested on internal combustion engines and will provide some general insight into test techniques.

14-1.1 INTERNAL COMBUSTION ENGINES, GENERAL TESTING

As a general approach to test accessibility for reciprocating piston internal combustion engines, one should consider the engine installed in its vehicle and its subsequent maintenance philosophy. The designer must consider the levels at which maintenance will be conducted, the depth to which test and diagnostics will be performed and the concepts for repair and replacement. The objective is to define the engine parameters which will require monitoring at any possible level of maintenance, so that access to measurement points can be assured.

Figure 14-1 presents a structure for the systematic analysis of engine test requirements. The two basic functional categories are:

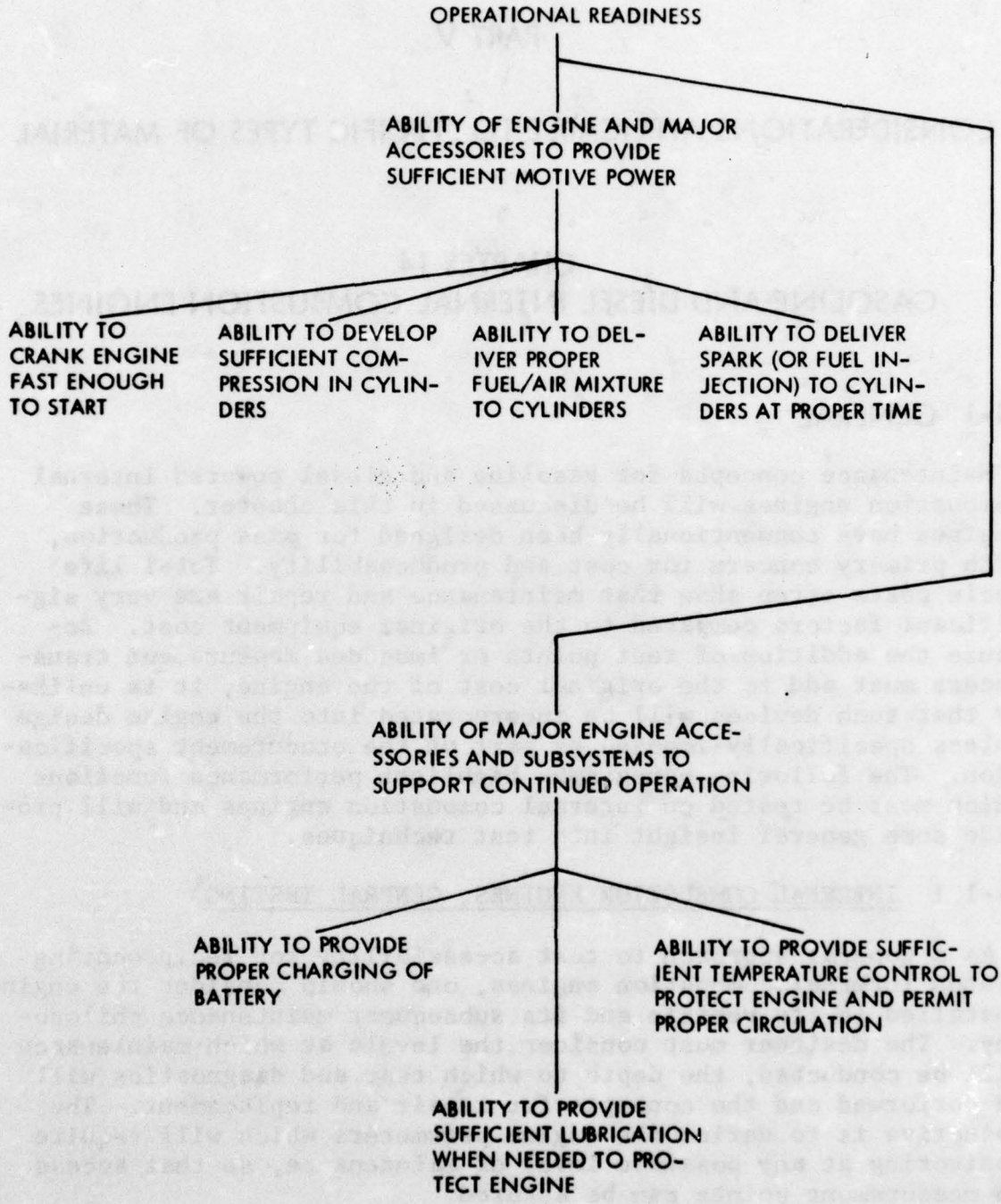

Figure 14-1. System Level Requirement for Engine Operational Readiness

(1) the ability to perform the immediate mission
(2) the ability to sustain prolonged operation.

The diagram further branches into performance functions as related to subsystems of the engine. When studying the test requirements for an engine, it is recommended that the functional performance requirements should be used as the starting point. Lists of engine conditions which fail to meet the functional requirements (malfunctions) can be derived for all possible modes of failure. Methods of detecting these malfunctions and the necessary instrumentation will complete the analysis.

The first category of performance functions in Figure 14-1, those pertaining to the ability of the vehicle to perform its immediate mission, have a significance in the normal concepts of vehicular maintenance. These are the functions which the user of the vehicle will normally evaluate in the process of vehicle operation, at least when the functions have degraded to the level of notice. It is characteristic of vehicle design that gradual degradation of performance is far more common than abrupt catastrophic failure. The operator may therefore be aware of performance degradations well in advance of the final failure threshold. When these degradations will be reported or detected depends on the procedures established at the user level. In cases where different operators are assigned to vehicles for each mission, there is less opportunity for user feedback. The only sure solution to early detection of degradation of performance is frequent maintenance tests. If the vehicle is equipped with accessible test points, a quick check automated diagnostic test can be planned as the standard means for maintaining the health of the vehicle.

The second category of performance functions in Figure 14-1, those pertaining to the continued ability of the vehicle to sustain operation, are normally associated with preventive maintenance practices. It is normal to check lubrication levels, change lubricants, clean filter, etc. on a periodic basis. However, there are also functions within this category which are not tested in the normal scheduled maintenance because of a lack of test accessibility. Performance of the charging system, internal lubrication, control of temperature of coolants and lubricants, and pumping capacity are prime examples. For example, if the charging system is undercharging the battery, the vehicle will soon fail to start; if it is overcharging the battery, it will ruin the battery. Insufficient lubrication will cause severe internal engine damage and faulty temperature control could either foul the engine (from constantly running too cold) of even cause serious internal damage if the engine overheats. On some vehicles,

dashboard monitoring devices are provided to give the operator some indication of the operation of charging, oil pressure, and coolant temperatures. To be certain that degraded operation will be detected, measurement access must be provided so that periodic tests can be recorded, and the maintenance concept must include scheduled tests. For these tests to be economically justified, access to test points must be quick and easy.

In the following discussions, engine testing will be discussed at the level of overall performance evaluation. Diagnostics for the purpose of fault isolating so that the faulty component can be repaired will also be discussed. A number of test parameters which can be used in each type of test will be discussed.

14-2 SPARK IGNITION ENGINE TESTING

14-2.1 PERFORMANCE TESTS

The first engine performance test will normally be a check of the idle condition consisting of checking the idle speed and speed variation. The value of the information gained depends on the availability and quality of both test points and test equipment. Gross speed variations such as those caused by lean fuel/air mixtures can easily be detected by simple manual tests with a tachometer. Cylinder to cylinder speed variations such as those corresponding to a single cylinder misfire require more sophisticated test techniques. The test parameter best suited for this examination is the ignition points voltage (or similar signal from solid state ignition signals), since the rotation of the engine is directly translated into a cam rotation which interrupts the ignition contacts. If the measurement system measures the average of a train of pulses derived from this test point, information concerning the average speed of the engine, and speed excursions having a time duration of greater than one (1) second, can be recorded. If the measurement is made on the time interval between successive contact interruptions, cylinder to cylinder speed variations can be detected. The measurement system must be able to detect a reference (e.g. firing of cylinder No. 1) in order to associate firing deviations with a particular cylinder.

A second major measure of performance for a spark ignition engine is its power generating capability. Conventional methods for evaluating this are:

(1) A road test (highly subjective)
(2) A chassis dynamometer test.

The chassis dynamometer test is superior to other tests because power output can be recorded under controlled conditions of load and engine speed. However, the necessary equipment is expensive and the process can be time consuming. A simple and effective alternate test has been devised, using ATE. This requires that electrical connections from the ignition be made available, so that the spark can be inhibited on any selected cylinder(s) in any desired firing pattern, permitting the engine to be run open throttle without overspeeding. Air to fuel ratio and related parameters can subsequently be evaluated. Performance of individual cylinders can also be evaluated with the above technique.

14-2.2 FAULT ISOLATION TESTS

Fault isolation on the engine fuel delivery, power generation, lubrication and coolant subsystems is discussed in this section. Electrical functions (starter, ignition, and charging) will be covered in a subsequent section.

One of the key areas of fault isolation within any reciprocating piston internal combustion engine is that of the compression-related parts of the block and head. Problems in this part of the engine typically result in low power and low compression, excessive oil consumption, or oil contamination. The engine designer should consider the following:

(1) What failures or malfunctions are apt to be problems in this part of the engine?

(2) At what maintenance level will these problems be corrected?

(3) Based on expected problems and corresponding maintenance levels, what level of fault isolation is really desired before starting disassembly or repair action?

(4) What parameters should be made easily accessible to the mechanic to quickly achieve desired level of fault isolation?

Table 14-1 illustrates a method for analyzing these requirements and deriving test point lists. Only a few representative malfunctions are listed and a complete analysis would cover many additional entries. However, it should be noted that the level of fault isolation will generally be quite limited, because of the limited options in the repair of the engine.

For all malfunctions involving internal engine components, isolating the fault to either the block or the pistons is usually sufficient. The engine must be pulled from the vehicle for rebuild or overhaul if the problem is pistons, rings, block, or most any other part inside the block. If the problem is in the head, it may be repairable without pulling the engine. However, it usually does not matter whether the fault is in the head, gasket,

TABLE 14-1. SAMPLE TABLE OF TEST FUNCTIONS AND DERIVED TEST MEASUREMENT PARAMETERS

PERFORMANCE FUNCTION OR SYMPTOM	MALFUNCTION	DESIRED LEVEL OF ISOLATION	TEST PARAMETERS
Low Power and Low Compression on one or more Cylinders Excess Oil Consumption Contaminated Oil	Cracked Head Leaky or Blown Head Gasket Sticky or Burned Exhaust Valves Sticky or Burned Intake Valves Broken Valve Springs Worn Valve Stems or Guides Improper Valve Clearance Worn Rings or Cylinders Stuck, Seized or Broken Rings Cracked or Broken Piston Cracked Block	Head or Head Gasket Block or Pistons	Starter Current Blowby Pressure Cylinder Correlation Signal Intake Manifold Vacuum Exhaust Pressure

or valves, the head will be removed (except for valve adjustment problems) and visual/mechanical inspection techniques can quickly isolate the problems. On multiple head engines (such as any V block) it is desirable to identify the faulty cylinder or cylinders so that only the problem heads need to be pulled and rebuilt.

Test parameters which are particularly useful for this type of isolation are shown in Table 14-1.

The starter current can be evaluated by an automatic test system to detect low compression on a cylinder-by-cylinder basis. This is possible by the evaluation of the starter current waveform in the time frame of individual cylinder compression strokes. The engine must be inhibited from firing during the test. The compression reached in each stroke causes the starter motor current to be a measure of compression. Cylinder-by-cylinder comparisons are readily derived, such that one or more weak cylinders could be detected. The need for automatic processing to evaluate this type of data is apparent, since the duration of the test must be short to avoid stressing starter motor and battery and the waveform is not easily presented for manual interpretation.

Other signals useful in diagnostic evaluation of the engine include blowby pressure, intake manifold vacuum, and exhaust pressure. The blowby pressure can be measured on some engines to diagnose if the fault is in the head or the block, since gas blowby into the crank-case indicates a problem with worn rings, a cracked piston, or other malfunction which will necessitate the removal of the block. The intake manifold vacuum signal can be used to detect worn valve guides and stems, and unnecessary valve adjustment can be avoided. Measurement of the exhaust pressure is further useful in differentiating between intake and exhaust valve faults and is sometimes used to detect high exhaust backpressure. The values of starter current, intake manifold vacuum, blowby pressure, and exhaust pressure, are especially effective if the test system can evaluate the variations in waveform on a cylinder-by-cylinder stroke basis. This in turn implies that a waveform evaluation type system is employed, and that all waveforms can be referenced to the order of cylinder firing. The basis for effective engine diagnostics lies in the ability to measure these parameters on several such signals and to cross-correlate the symptoms. The objective is to diagnose the malfunction in order to determine which part of the engine to disassemble, since the components involved are largely internal to the engine and the major repair effort is in the disassembly process.

In the fuel delivery, lubrication, and cooling susbystems of the engine, there is a better chance for diagnosing the malfunction to a single replaceable component, such as a pump, filter, hose, etc. Such components can usually be replaced without major disassembly of other engine subsystems. The signals typically required for diagnostic purposes are the pressures at the output of fuel, oil and water pumps, and the carburetor inlet pressure. Pressure drops in the fluid distribution lines are also of importance, especially the drop across filters. The true value of these signals will not be realized unless the measurements are correlated with controlled engine operating conditions. Only in this way can pump capacities be checked over the full range of engine speed and load, for instance. Carburetor fault isolation often can be reduced to a logical process of elimination, in that fuel pressures are normal, the engine has no compression faults, and spark ignition is good, therefore the carburetor may be assumed to be the cause of poor engine idle or poor power performance. The difficulty of measuring the delivered mass rate of flow and fuel-air ratio from the carburetor makes this elimination process necessary.

A spark ignition engine lubrication system may include an oil sump, pump, filter, pressure relief valve, cooler, and flow passages. The oil pressure itself is usually included as a dashboard monitored parameter and acts as an indicator of oil pump and pressure relief valve operation. However, oil filters and coolers often are difficult to test and careful considerations should be given to providing access points for differential pressure readings across the oil filter and differential temperature readings across the oil cooler.

The cooling system also requires consideration. Typical problem areas include the radiator, pump, thermostat, and general heat transfer within the engine block. Key test parameters include radiator input temperature, differential temperature measurements across the radiator, and system pressure. Loss of system pressurization capability indicates a leak somewhere in the system. Access for one point of measurement can be easily connected through the radiator cap. Temperature measurements can be used to check thermostat operation and system thermal efficiencies. Access for block coolant temperature and radiator differential temperatures should be provided elsewhere in the coolant path.

14-3 CHARGING SYSTEMS

The two primary concerns of any automotive charging system are the charging current and the regulation voltage. These two

functions are normally left quite unattended until battery problens develop; and even then, the solution is often to install another battery. If the regulator voltage is set too high, the battery will be overcharged. This causes the battery to overheat, which in turn causes rapid evaporation of cell water, and ultimately, short life of the battery. On the other hand, the results of an undercharged battery are much more obvious. Little reserve for starting is the first indication, with the ultimate indication being a dead battery.

Charging system parameters are shown in Table 14-2 and Figure 14-2 illustrates a simple charging system. Depending on the charging system complexity, maintenance goals, and vehicle cost, varying degrees of monitoring complexity may be installed. Since most charging systems are rated by current capacity, the operator/alternator output current should be monitored directly via a shunt in series with the output or a loop made available for a clamp-on current probe. Battery voltage in itself is simple enough to monitor in a properly working system, but in a malfunctioning system, cables or clamps may be the problem. Thus, voltage monitoring points must be selected with a certain amount of discretion. The battery voltage should be monitored right at the battery posts themselves, and not at the clamps. This will enable one to determine the status of the clamp connection and cable drops to the battery by monitoring the clamps with respect to vehicle ground and generator or alternator output. Test lines attached to the generator/alternator output and return should be capable of handling the full output current, thus providing a means for external loading. (The battery itself may be used as a momentary load after it has been discharged.) The return lines for the generator/alternator and the regulator should also be monitored for excessive voltage drops.

Regulation schemes in charging systems are many and varied. Some systems monitor battery voltage only, while other monitor the voltage and charging current. Since the ultimate purpose of the regulator is to control the field winding, the voltage across the field and the current through it should be made available for test. Additional parameters of importance are the regulator input voltage, input current and output voltage.

Temperature is another prime consideration when testing charging systems. In many charging systems, the charging voltage varies inversely with temperature as controlled by the regulator. Thus, the temperature of the regulator is required for meaningful charging voltage tests. Battery temperature is also important as

TABLE 14-2. TYPICAL PARAMETERS FOR CHARGING SYSTEM TESTS

Battery Voltage
Alternator/Generator Output Voltage
Alternator/Generator Output Current
Field Voltage
Field Current
Engine RPM
Charging Current Waveform
Battery Cell Electrolyte Level/Specific Gravity
Cell Voltage Ratio
Battery Temperature
Regulator Temperature
Cable and Terminal Voltage Drops

damage can result from overheating. In addition, if the battery temperature is known and the battery has neither been charged nor discharged within the past twenty-four (24)hours, its state of charge may be determined by a simple voltage measurement.

More direct monitoring of the battery is possible with the addition of probe(s) into a battery cell or all cells. The introduction of a lead probe into a single central cell will provide an electrolyte level sensor. If identical probes are introduced into each cell, cell-to-cell voltage ratios may also be taken to provide a relative check for bad cells. Probes to make specified gravity tests of each cell using voltage measurement are currently under investigation and may provide a useful cell monitor for future applications.

14-4 IGNITION SYSTEMS

The spark ignition system is one of the greatest sources of poor engine performance, and it is also one of the most difficult to test with conventional equipment and techniques. The average mechanic has few effective tools for this purpose. Manual ignition testers often prove difficult to use and hard to interpret. Ignition problems are often solved by trial and error component replacement.

Advanced test techniques have been developed which permit the ignition system to be evaluated with a high degree of validity. Proper test point access and test signal conditioning is

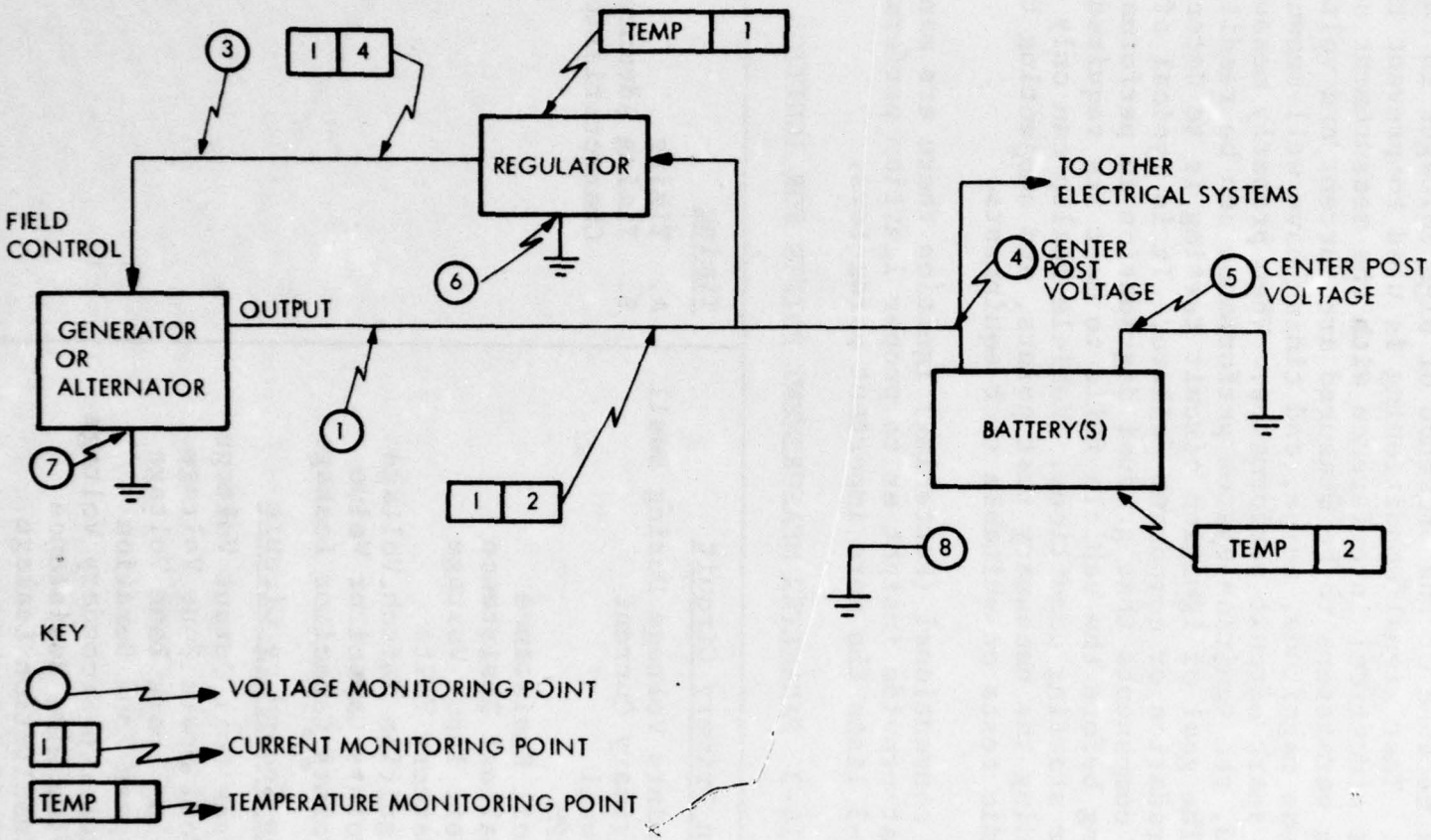

Figure 14-2. Charging System Block Diagram

essential because of the presence of high voltages in the spark circuits. Test signal conditioning is used to prevent the possibility of electrical interference with the measurement circuits. The basic parameters to be measured are current and voltage waveforms whose magnitude, shape, and timing have well-known relationships to spark circuit performance. When properly measured and evaluated, the ignition system performance can be readily determined. The goal of ignition circuit testing is to detect performance degradation or component failure. It is typical of most ignition components that gradual degradation in performance will occur long before the vehicle fails to meet its required speed, power, or starting conditions. Vehicle health can only be assured by providing the necessary test points, and subjecting the vehicle to periodic tests on suitable test equipments.

In the conventional (Kettering) ignition there are many parameters that provide insight as to proper ignition performance. Table 14-3 lists the more important parameters.

TABLE 14-3 PARAMETER MEASUREMENT POINTS FOR IGNITION SYSTEMS

Ignition Primary Circuit	Timing
A. Points Voltage During Dwell	A. Timing
B. Primary Current	B. Timing Advance Characteristics
C. Dwell	
D. RPM	
E. Coil Resistance	
F. Ballast Resistance	
G. Coil Input Voltage	
H. Battery Volts	
I. Ignition Switch Voltage	
J. Points Capacitor Value	
K. Points Capacitor Leakage	
Ignition Secondary Circuit	
A. Peak Coil Output Voltage	
B. Coil Spark Zone Voltage	
C. Plug Spark Zone Voltage	
D. Spark Zone Duration	
E. Reserve Secondary Voltage	
F. Plug Wire Resistance	
G. Insultation Leakage	
H. Misfire Leakage	
I. Engine Angular Index/Synchronization	
J. Secondary	

In the primary ignition circuit, many of the parameters are interrelated and all need not be measured individually. Coil and ballast resistance are examples. If the primary current and voltages across these devices are known, then the resistive value is found through Ohm's law. The integrity of the points capacitor may be determined by observation of the primary waveform. Using such logic, a few key test points can be identified for both primary and secondary circuits. Table 14-4 lists these key test points, in order of relative importance. In some cases the means of instrumentation has been indicated to convey the type of test signal required.

TABLE 14-4. KEY ELECTRICAL TEST POINTS FOR IGNITION SYSTEMS

Ignition Primary Circuit
A. Points Voltage
B. Coil Input Voltage
C. Ignition Switch Voltage
D. Battery Voltage
E. Shunt or Current Probe Access to Primary Coil Current
Ignition Secondary Circuit
A. Coil Output Voltage
B. No. 1 Plug Voltage
C. Secondary Current via Torroid
D. Remaining Plug Voltages

The secondary side of the ignition system contains the information as to whether or not the ignition system is delivering the proper amount of energy to the plugs at the proper time. In addition, some primary faults may be determined by analysis of the secondary test points.

Since many ignition problems become evident only under adverse conditions, the system in general must be scrutinized in detail under normal operating conditions. For example, a low dwell angle will result in normal operation at idle and low speeds. However, at high engine speeds under load, misfiring will occur since insufficient energy is stored in the coil. A bad set of points will exhibit erratic performance which, if not examined electrically in detail, may go undetected if they are not causing misfires at the time of test. Thus, convenient access to key ignition parameters, along with the proper test equipment, will enhance both maintainability as well as vehicle reliability.

Figure 14-3 illustrates a conventional ignition system with key test points. These points are ranked by number as to overall importance and cost with the lower numbers indication higher importance and lower implementation costs. A few general words of caution are offered regarding the implementation of such a test-point scheme. First, due to the spectral content of ignition systems in general, the layout and shielding must be designed to minimize radiated interference which could effect the vehicle, the test engine, or neighboring equipments. Second, ground referencing for the measurement or diagnostic system attached to the vehicle must be considered. This is especially important for small signals such as the voltage drop across the ignition points in the closed position. This voltage normally runs in the tens of millivolts range and should be a differential voltage measurement with respect to points ground. If high voltage dividers are used for secondary waveform measurement, these ground connections must be carefully considered because of the large energy present during the spark.

Electronic ignition systems are many and varied with the coil primary drive electronics being the area of greatest difference. Here, the input signal interface from the distributor to the electronics may be mechanical points, electromagnetic, or electrooptical, with the power circuitry ranging from discrete components to hybrids. Measured values on the coil primary and the secondary side are still essentially the same; however, detailed consideration of the electronics and packaging is necessary to provide meaningful test points. Sufficient access to the electronics to determine major module replacement and system performance should be provided. In all cases, the input and output of the electronic module should be made available.

External control of the ignition system is also desirable. This enables testing of the ignition system without running the engine and also allows individual, groups, or all the cylinders to be disabled for power, power balance, and cranking tests. In the case of conventional ignition systems, this is accomplished by putting a solid state switch across the points. As for electronic ignition systems, those which have a simple transistor coil drive may be inhibited in the same manner as the Kettering system. Those systems which have more exotic ways of driving the coil should be equipped with a low power access point to provide the external control.

Ignition timing is another area where convenient parameter access can result in a time savings and an increase in performance and reliability. If the vehicle is equipped with a mechanism such

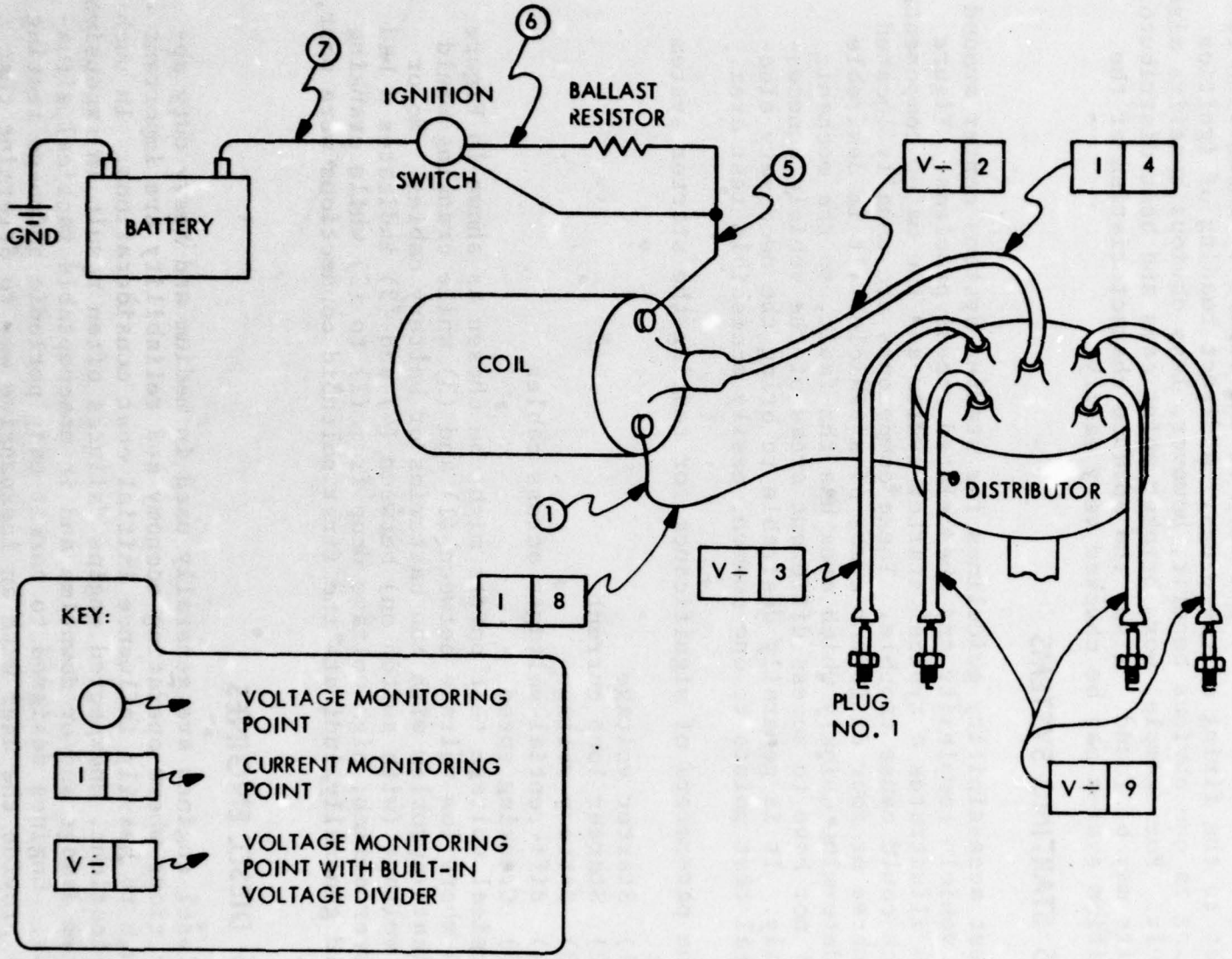

Figure 14-3. Conventional Ignition System with Key Test Points

as a magnetic pickup or other encoding scheme on the engine crankshaft, then the relative position of the engine is known with respect to the firing of the plugs. A direct reading of ignition timing is one obvious benefit; however, less obvious benefits also result. For example, worn breaker point cams and bent distributor shafts may be found. Also, the advance characteristics of the ignition system may be checked very easily.

14-5 STARTING SYSTEMS

Test accessibility guidelines for starter systems center around the vehicle complexity and the related access problems. Figure 14-4 illustrates a typical starter system and the major components which could cause trouble. These components are usually located in three or four different areas of a vehicle. It is desirable to determine quickly which area has the fault, so the mechanic will not have to access different areas of the vehicle unnecessarily. It is generally desirable to bring the necessary electrical test points to one common, easily accessible test area.

The parameters of significance for testing the starter system are:

(1) Starter voltage
(2) Starter loop current
(3) Battery voltage
(4) Differential voltages across cables
(5) Cranking speed

Typical voltage test points might be chosen as shown in Figure 14-4 where low voltage between (1) and (3) while cranking would indicate aproblem with the batteries or battery cables. No or low voltage (with switch on) between (4) and (3) indicates a bad starter switch; high voltage drop from (1) to (2) while cranking would generally indicate the first solenoid connections were poor, etc.

14-6 DIESEL ENGINES

Diesel engines are generally used in medium and heavy duty applications where operating economy and reliability are important enough to heavily influence initial cost considerations. In such applications, unexpected engine failures often result in expensive system damage and/or downtime and in unacceptable tactical situations. Engines designed to permit easy periodic go/no-go testing will provide the user with an inexpensive way to determine that critical power plants will function reliably between maintenance intervals. Easy access to test points reduces the costs of engine

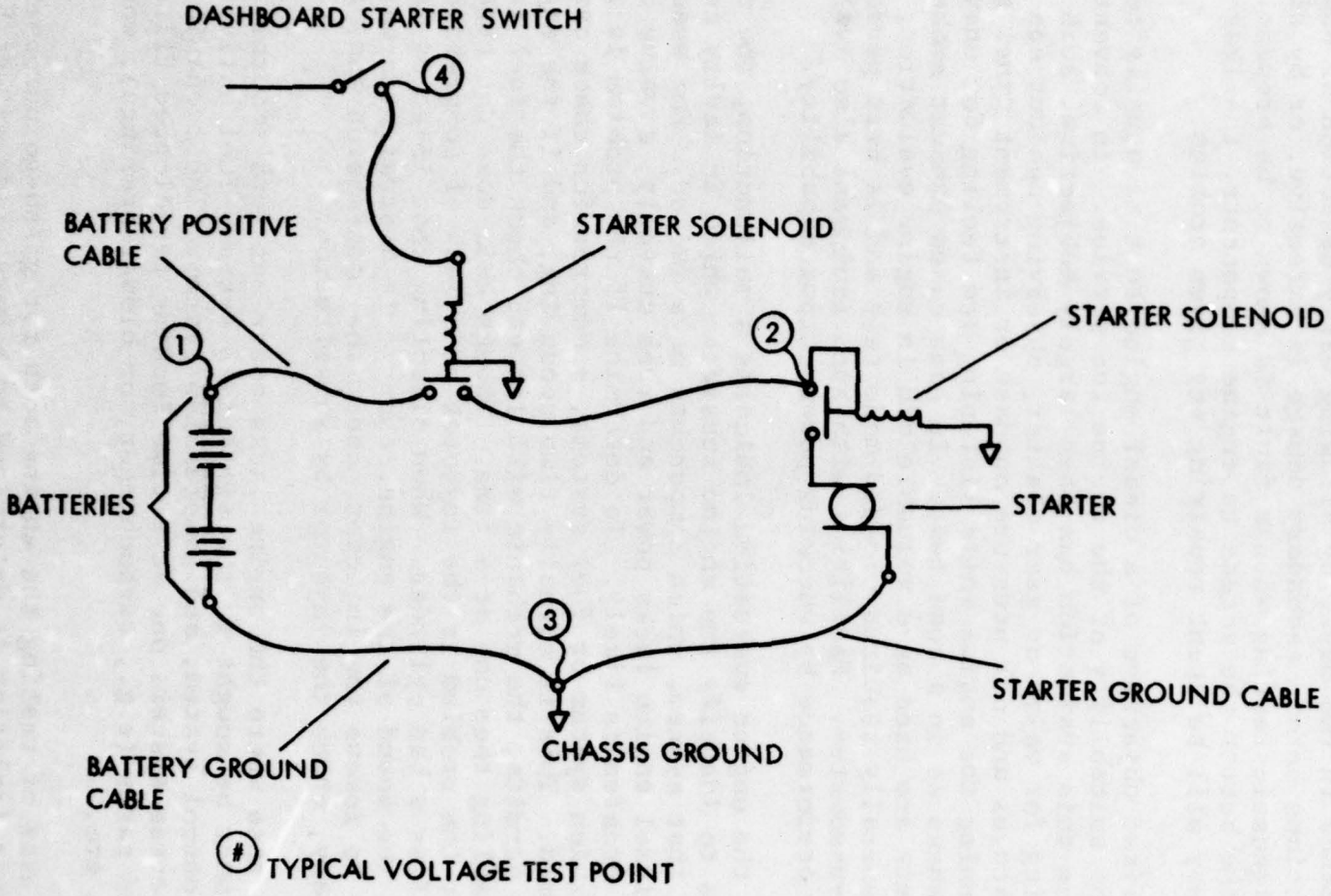

Figure 14-4. Typical Starter System

maintenance in two ways, by allowing early detection of engine malfunctions before secondary damage is extensive, or by simplifying diagnostic testing when a fault is known to be present. Further, the better the access to engine components, the less time and money will be spent repairing any given problem.

The first objective of a diesel engine test is usually to determine the suitability of the engine for service. In conventional practice this evaluation has been largely subjective, such as listening for valve or gear clatter, observing coolant and oil temperatures and oil pressure on dash or instrument panel gauges, and running the engine while listening and feeling for unevenness or weakness as in a road test. In some cases exhaust smoke measurements are used as a valuable aid in engine evaluation, but this generally requires a loaded-mode test and is best performed on a dynamometer. Facilities with such equipment also evaluate engine performance by checking power output capability.

When the engine evaluation indicates a malfunction, the next step is to identify the engine subsystem which is faulty and, within that system, which components have failed. For example, if a diesel engine lacks power and runs unevenly, a valve or injector problem is likely. To determine if the problem is in the compression system or fuel systems, a compression check can be performed. This is normally time consuming, and if the engine design permits, the mechanic will instead check the fuel injectors by disabling them one at a time. Though this does not reveal whether the problem is the injector or a lack of compression, it identifies a bad cylinder. When disabling that injector fails to change the sound of the engine, then it is a straightforward procedure to remove the injector, check the compression and, if necessary, check the injector by substitution.

In a case where the engine lacks power but runs smoothly, the fault must be sought in the air intake system, fuel delivery, fuel control system, and compression system. The mechanic will check these systems one at a time looking for clogged filters, damaged parts (e.g., turbocharger, or blower bearings), worn rings, etc.

The ease of testing the engine both for go/no-go purposes and for fault isolation is determined to a very great extent by the availability of engine parameters for measuring, by either automated or manual test equipment. Improved access to test points will result in lower test and maintenance costs.

A very important engine parameter in the evaluation of performance is the crankshaft angular velocity. Although diesels often contain some form of tachometer, the most valuable information is in the variations in crankshaft speed over the time duration of single compression strokes. Therefore the information bandwidth of the signal must be adequate to permit this type of evaluation. In addition, the signal must be correlated in time to the occurrence of at least one cylinder's top dead center, so that each cylinder can be identified in the analysis of the measured waveform. This type of measurement is ideally suited for automatic equipment to analyze, since data can be obtained during short intervals and transient conditions, which would not be practical on manual, steady-state measurement instruments. Weak cylinder power, misadjustment of the governor, and poor engine power generating capability can all be detected by crankshaft velocity analysis. On engines not having turbocharging, the inertia of the engine can be used as a short term load, and the ability of the engine to accelerate from idle can be correlated to the power generating capacity. Effects of friction and accessory loads may be accounted for by measuring the rate of deceleration at the conclusion of the acceleration burst. Obviously, the technique requires a test system which can process the short-duration transient type measurements.

As already indicated, a signal must be provided to indicate top dead center of one particular cylinder or a known position of the crankshaft and camshaft in the engine cycle. The signal should occur once every two crankshaft revolutions to permit positive identification of the compression stroke, except in the two stroke cycle engine where the compression stroke occurs on every crankshaft cycle. In order to provide useful diagnostic information, the accuracy of the signal with respect to top dead center should be approximately 1/4 degrees.

Instrumentation of the crankshaft speed signal could be made with a magnetic (proximity) type pickup mounted near a suitable gear in the engine. The pickup will sense the passage of each gear tooth and produce a pulsed signal in response. This type of device has the advantage of requiring no electrical power for stimulus, as the pulse can be interfaced to a suitable external signal amplifier in the test equipment. The gear must have a sufficient number of teeth to produce a signal with sufficient information to permit the analysis of cylinder-to-cylinder speed variations. The flywheel ring gear is one possibility.

A typical flywheel ring has 200 gear teeth. Therefore it will provide 50 pulses during a single power stroke on an 8-cylinder engine. This would result in a 10KHz pulse signal at 3000 RPM engine speed.

Liquid cooled diesels have the additional requirement of evaluating the coolant system. A manual temperature gauge will often be provided. For rapid and effective testing of the system, there should be access to both temperatures and pressures in the cooling system.

In addition to monitoring the coolant temperature and the measurment of dynamic pressure, variations in these parameters are useful in detecting coolant leaks in the block and head gasket or head seals. Access to the cooling system can be gained through a boss in the cylinder head with a standard thread such as National Pipe Thread (NPT). The boss should be positioned in the system in such a way that the coolant flow does not deposit scale or sludge against the pressure tap.

The lubrication oil pressure should be made available at the pump output by positioning an access port near the inlet to the oil filter. An access port should also be provided at the oil filter outlet to allow the pressure drop across the filter to be checked to detect filter blockage.

In the military environment where fuel quality and cleanliness may vary considerably, it is also important to have access to the output pressure of the primary fuel pump and the pressure drop across the primary fuel filters.

In the cooling, lubrication and primary fuel systems, providing access to test points will range from simply providing a tapped, plugged boss for each test point in low cost installations to providing quick-disconnect fittings for attaching test equipment in high cost equipment where reliability and maintenance are critical.

Other pressures which are of interest in engine evaluation and diagnosis are the intake and exhaust manifold pressures and the crankcase pressure. For use with simple test equipment, these three test points provide data to show air cleaner, turbocharger, exhaust system and piston ring condition. An automatic diagnostic system would use this data correlated with engine speed and crankshaft position data to identify individual cylinder, valve and ring malfunctions.

Accessibility to engine test points is determined not only by engine design but also by how the engine installation is configured. An important part of making an engine easy (therefore inexpensive) to test effectively is making the engine easy to reach. Many important measurements such as oil pressure or crankcase pressure must be performed with the engine running. It is therefore desirable to maximize the available working space around the engine in its operating position. This not only simplifies testing, it greatly facilitates maintenance action. Ease and reliability of maintenance can also be augmented by positioning engine accessories in a way that interferes minimally with routine maintenance work. For example, if an air intake duct has to be removed to remove a valve cover to adjust the valves, this will increase the time required to perform the valve adjustment and increase the probability that it will either not be done or will be done incorrectly. Of course, requirements for armor and for space saving can severely limit the designers choices, but from the point of view of testing and maintenance, ease of access to test points and simple physical access to the engine and its accessories can be worth much in total engine life costs.

14-7 CANDIDATE ENGINE TEST POINTS

There are numerous test points which the designer may select for the purpose of engine test, however, and the final selection of test points rests with the judgment of the designer, the peculiar design of his engine, and the maintenance goals which he is trying to serve.

Table 14-5 presents a list of test parameters from which the equipment/vehicle designer may select those which seem to him to provide the kinds of data useful to diagnostic testing. In addition, certain of these parameters are known to be particularly useful in the testing of internal combustion engines from state-of-the-art work currently in progress on computer-controlled diagnostic testing. These parameters are marked by a note number with the note listing at the end of the table.

TABLE 14-5. CANDIDATE TEST POINTS, GASOLINE AND DIESEL ENGINES

1. Engine Mechanical Systems

   a. Access to flywheel ring gear or other high-resolution crankshaft position signal for mounting pick-up. (See Note 1)
   b. Access to any signal which identifies a unique position of the mechanical system during each engine cycle. (See Note 2)

2. Engine Intake System

   2.1 Normally Aspirated-Gasoline

      a. Pressure tap at aircleaner exit to determine air cleaner element restriction.
      b. Pressure tap at intake manifold to determine carburetor restriction and condition of valves.

   2.2 Single Stage Supercharged Aspiration-Gasoline

      a. Pressure tap at aircleaner exit to determine air cleaner element restriction.
      b. Pressure tap at supercharger intake to determine carburetor pressure drop.
      c. Pressure tap at intake manifold to determine supercharger delivery pressure.

   2.3 Two-Stage Supercharged Aspiration-Gasoline

      a. Pressure tap at aircleaner exit to determine air cleaner element restriction.
      b. Pressure tap at turbocharger exit for turbocharger performance.
      c. Pressure tap at mechanically driven supercharger exit for second stage performance.

   2.4 Normally Aspirated Diesel

      a. Pressure tap at intake manifold for air cleaner restriction and valve condition.

   2.5 Single-Stage Supercharged Aspiration - Diesel

      a. Pressure tap at aircleaner exit to determine air cleaner element restriction.
      b. Pressure tap at intake manifold to determine supercharger performance.
      c. Pressure tap at air box to determine screen restriction.

TABLE 14-5. CANDIDATE TEST POINTS, GASOLINE AND DIESEL ENGINES (Continued)

2.6 Two-Stage Supercharged Aspiration-Diesel

a. Pressure tap at aircleaner exit to determine air cleaner element restriction.
b. Pressure tap at turbocharger exit for turbocharger performance.
c. Pressure tap at mechanically driven supercharger exit for second stage performance.
d. Pressure tap at airbox to determine screen restriction.

2.7 Single-Stage Supercharged and Intercooled - Diesel

a. Pressure tap at aircleaner exit to determine air-cleaner element restriction.
b. Pressure tap at supercharger exit to determine supercharger performance.
c. Pressure tap at intake manifold to determine heat exchanger restriction.
d. Temperature taps on heat exchanger to determine Td across element.

3. Engine Compression (See Note 3).

a. Small Engines - Single pressure tap in No. 1 cylinder head for compression check.
b. Large Engines - Pressure tap on all cylinder heads for compression check and decompression valves.

4. Exhaust System

4.1 Exhaust System-Normally Aspirated or Mechanically Supercharged

a. Exhaust manifold pressure tap for back pressure measurement.
b. Exhaust manifold temperature taps for cylinder temperature profile check.

4.2 Exhaust System - Turbocharged

a. Pressure tap in exhaust pipe after muffler for emission sampling.
b. Air pump delivery pressure tap for after-burning check.
c. Sampling tap in exhaust pipe before catalytic converter.

TABLE 14-5. CANDIDATE TEST POINTS, GASOLINE AND DIESEL ENGINES (Continued)

5. Exhaust Emissions

   a. Pressure tap in exhaust pipe after muffler for emission sampling.
   b. Air pump delivery pressure tap for after-burning check.
   c. Sampling tap in exhaust pipe before catalytic converter.

6. Crankcase Breathing

   a. Crankcase pressure tap for blow-by and positive pressure check.

7. Engine Lubrication System

   a. Pressure tap at supply pump delivery.
   b. Pressure taps at full flow oil filter entry and exit for filter element check.
   c. Pressure taps at oil cooler entry and exit for cooler restriction check.
   d. Pressure tap at scavenge pump delivery.
   e. Pressure tap to determine mechanical supercharger supply pressure.
   f. Pressure tap to determine turbocharger supply pressure.
   g. Pressure tap to determine piston cooling jet supply pressure.
   h. Pressure tap to determine fuel injection pump supply pressure.
   i. Pressure tap to determine auxiliary oil filter exit pressure.
   j. Temperature tap at oil pan or main oil gallery to determine oil temperature.
   k. Temperature tap at turbocharger exit for bearing temperature check.
   l. Location provided for oil level sensor in oil pan.

8. Engine Fuel System

   a. Pressure tap primary and secondary fuel filter intake.
   b. Pressure tap primary and secondary fuel filter exit.
   c. Fuel transfer pump delivery pressure tap (for distributor and inline injection pump systems).
   d. Delivery pump supply pressure tap (for unit injector and P.T. systems).
   e. Pressure tap in distributor injection pump hydraulic head for injection pressure.

TABLE 14-5. CANDIDATE TEST POINTS, GASOLINE AND DIESEL ENGINES (Continued)

f. Pressure tap in injection lines for inline injection systems.

9. Engine Cooling System

9.1 Liquid Cooled (Automotive)

a. Temperature tap in system before thermostat/s.
b. Temperature tap in system after thermostat/s.
c. Temperature tap in system after radiator/s.
d. Pressure taps at pump entry and exit.
e. Pressure and temperature taps in multiple heads and distribution header. (See Note 4).
f. Location in radiator top tank for liquid level sensor.

9.2 Air Cooled

a. Air inlet (duct) temperature tap.
b. Air outlet temperature before and after thermostatically controlled shutters.
c. Air velocity tape at air intake and exit.
d. Cooling fan/s speed pick up tap for variable speed or thermostatically controlled fan drives.
e. Temperature taps at oil cooler entry and exit points for both air and liquid.

10. Engine Starting System

10.1 Electric Starters

a. Provide access to starter supply cable for current measurement. (Note 5)
b. Provide access to starter positive terminal for voltage measurement. (Note 6)

10.2 Air Starters

Pressure tap at air supply or exhaust port to measure supply pressure. (Note 5)

TABLE 14-5. CANDIDATE TEST POINTS, GASOLINE AND DIESEL ENGINES (Continued)

NOTE 1:	An automated test instrument can use a high resolution crankshaft position signal to determine engine speed continuously during cranking and running. This allows detailed evaluation of cylinder compresssion and power producing capability.
NOTE 2:	This signal will synchronize the test system with the engine so that when engine faults are detected the system will be able to specify in which cylinder they are occurring.
NOTE 3:	Particularly useful in cases where, for reasons of accessibility or personnel management, automated testing is preferable to manual inspection.
NOTE 4:	Applicable especially to higher cost installations. Can be used for continuous on-line engine monitoring to detect developing malfunctions. One temperature tap for each cylinder allows single cylinder fault detection and identification.
NOTE 5:	Allow automated test equipment to evaluate relative compression in engine cylinders. In the case of electric start systems, it also allows evaluation of battery/starter system integrity.
NOTE 6:	Is useful in diagnosing malfunctioning battery/starter systems.

CHAPTER 15
GROUND HYDRAULIC VEHICLE SYSTEMS

15-1 GENERAL

Hydraulic systems are found on ground vehicles primarily for one of two reasons:

(1) The convenient transfer of relatively large amounts of mechanical power from one location to another.

(2) The accurate and high power control of mechanical functions (high-pressure hydraulics permit wide band-width and accurate servo control).

When applying diagnostic testing to hydraulic systems, the following parameters represent those most useful, in order of importance:

(1) Pressure
(2) Speed (usually of the prime mover)
(3) Temperature
(4) Flow rate
(5) Particulate count in 100 milliliters of the fluid (the standard volume for this measurement).

The first four of these parameters are obviously useful in diagnostic testing for fault isolation. The fifth is becoming increasingly important in determining the rate at which components of the system may be deteriorating and therefore predicting the MTBF of the system.

An extensive discussion of the methods of measurement that are most appropriate to the use of ATE in hydraulic system testing is provided in Chapter 12.

15-2 TESTING WITH THE APPLICATION OF AN EXTERNAL HYDRAULIC SOURCE

In order to facilitate the test of a hydraulic system, it is sometimes desirable not to have to operate the prime mover to establish hydraulic pressure. Figure 15-1 shows those configuration features that are useful in external source testing applications. Note that no hand valves are involved that might be left open (or closed) inadvertently.

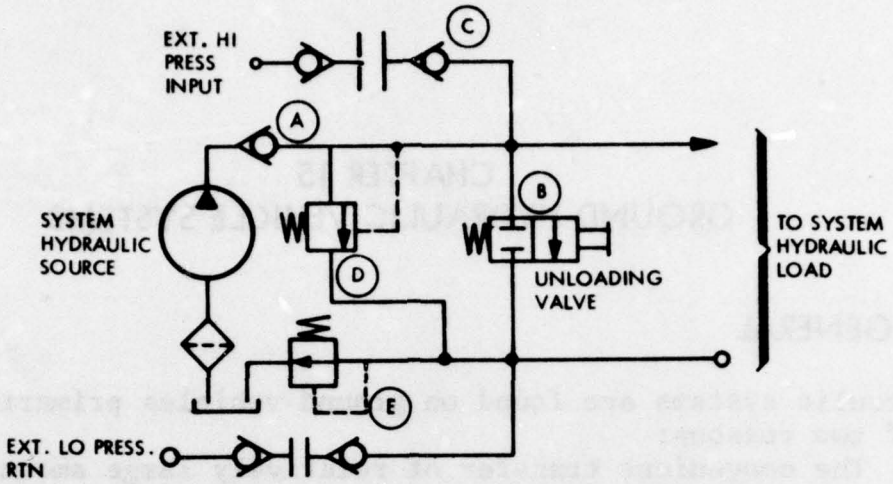

Figure 15-1. Testing Using External Hydraulic Power Sources

Features of the configuration shown in Figure 15-1 are:

(A) Check valves:
Permit easy access to the hydraulic load using an external hydraulic power source. No manual valves are needed and so cannot be left inadvertently in the wrong position.

(B) Unloading valve, manual:
Allows easy dump of hydraulic pressure before making external connection.

(C) Pressure-blocking disconnects:
Permits rapid connection of the external hydraulic source.

(D) System safety relief:
This relief must be located downstream of the high pressure check valve so that it is operative during tests with the external power source.

(E) Low pressure in-line relief prevents return to internal sump during operation with external source. (The external RTN line is held at a lower pressure than the setting of this relief.)

15-3 TESTING A SERVO CONTROLLED HYDRAULIC TRANSMISSION

The configuration of Figure 15-2 provides an example of the testing of a common type of hydraulic system, the hydraulic transmission. This is, in effect, a variable speed drive consisting of:

(1) A constant speed prime mover (often an induction motor or internal combustion engine)
(2) A variable stroke pump
(3) A constant displacement hydraulic motor

The normal mechanical output is bi-directional and its direction

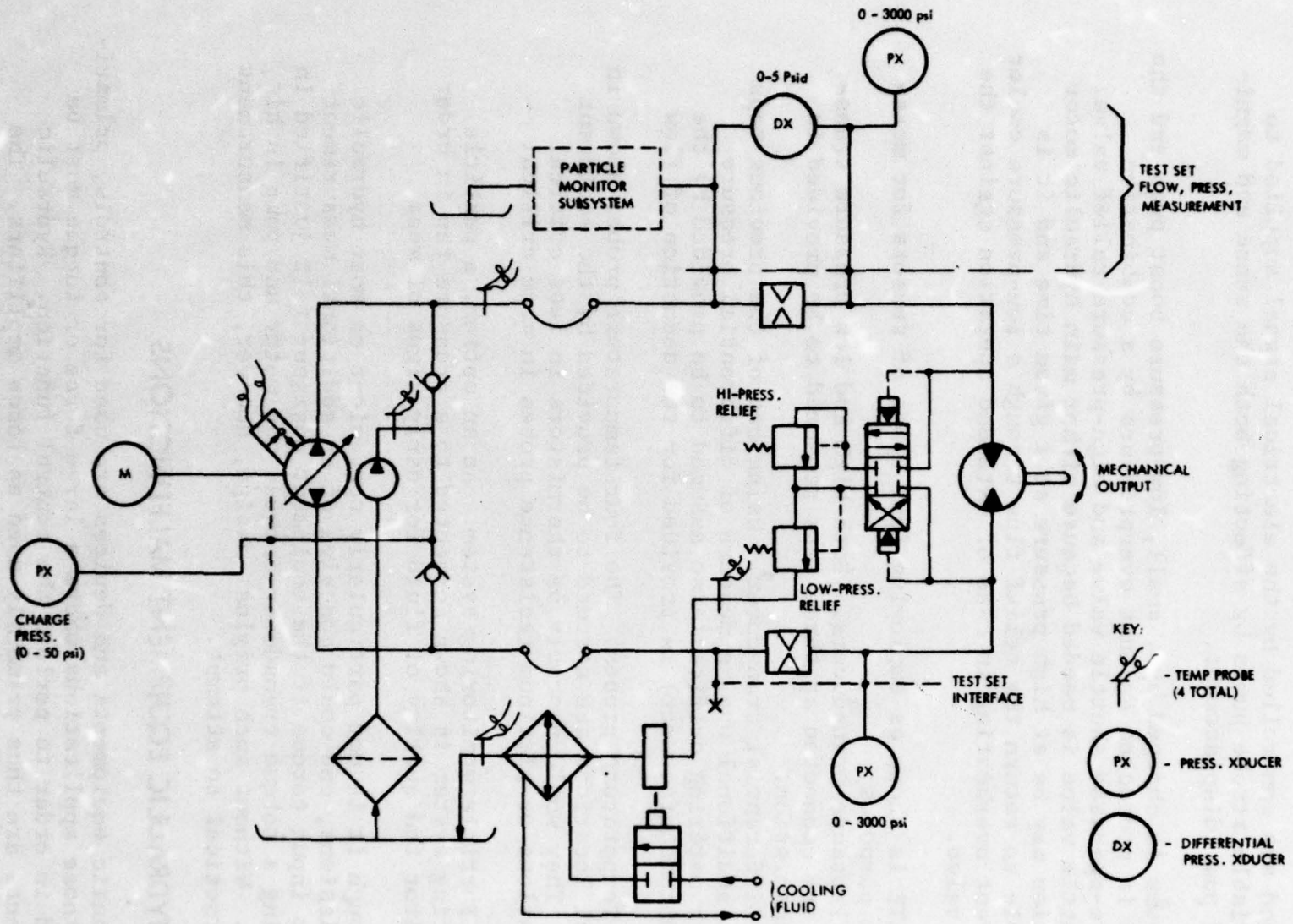

Figure 15-2. Typical Hydraulic Transmission

and speed are controlled by the electrical signal supplied to the variable stroke pumps by affecting both the sense and magnitude of pump displacement.

The pump is charged by a small, low-pressure boost pump and the circuit is protected against overpressure by a combination pressure-operated shuttle valve and high-pressure relief valve. The shuttle valve is needed because either main hydraulic motor connection may be at high pressure at a given time and it is desirable to return the relief flow through a low-pressure cooler to prevent overheating in case of extended operation against the relief valve.

The ATE is shown as employing four types of sensors for measurement purposes:

(1) Pressure transducers. Both high and low pressure transducers are connected at three taps presumed to be provided in the transmission.

(2) Differential transducer. Using one of the previous taps and one additional one, a measure of differential pressure across a metering orifice (also assumed to be provided by the equipment manufacturer) is provided for the deduction of flow rate.

(3) Temperature probes. The four temperature probes shown in critical locations are assumed to be provided by the equipment maker. They would probably be thermistors in less critical applications or platinum resistance probes in more critical cases.

(4) Particle monitoring system. As an option, a particle monitoring system is shown connected to a pressure tap in order to monitor the quality of fluid for early signs of wear.

Although it is not particularly convenient on most hydraulic transmissions, one could conceive of an additional measurement of pump input torque if the equipment designer felt justified in including a torque transducer between the motor and pump in his design. Without such original design, however, this measurement is impractical to attempt.

15-4 HYDRAULIC EQUIPMENT MALFUNCTIONS

Hydraulic equipments and devices are used for controls, primarily in those applications where a large force or torque must be applied in order to perform the control function. Hydraulic equipments are thus primarily used as force amplifiers. The common malfunction indications are sluggish and/or erratic

operation or failure to operate in one or more directions or modes of operation. Tables 15-1 and 15-2 list malfunctions indications, probable faults and parameters measured for fault diagnosis for two typical applications of hydraulic devices. These are, respectively, tank turret drives and howitzer recoil mechanisms. On the Tables, the measured values of each parameter are listed as N (normal), H (high), and L (low). Measured values for a parameter must be verified against the specific values and tolerances for a particular hydraulic device to determine whether they are normal, high, or low.

Where automatic test equipment or automatic data processing is to be used for complete fault diagnosis, it may be desirable to program all applicable malfunction indications in order to obtain as complete a diagnosis as possible. However, where diagnosis is performed manually using tables from a handbook, only the three or four most prominent symptoms should be indicated to minimize the burden of data collection and comparison by the repairman. This is generally sufficient as any malfunction affecting the parts of the hydraulic system requires disassembly and the specific failed part or component can then be determined by visual or instrument aided inspection.

15-5 CONSTRUCTION AND MATERIEL HANDLING EQUIPMENT MALFUNCTIONS

Hydraulic applications for construction and materiel handling equipment are used to perform the interaction between the controls and the drive trains. Table 15-3 lists common malfunction indications, probable faults and parameters measured for fault diagnosis for a typical construction and material handling equipment, a full-tracked tractor. The measured values of each parameter are listed as N (normal) H (high) and L (low) and must be verified against the specific values for each application.

15-6 TEST POINT SELECTION EXAMPLE

Table 15-4 presents a list of test parameters for construction equipment from which the equipment designer may select those which provide the kinds of data useful to diagnostic testing. Selection of these parameters should be made considering the equipments common malfunctions such as those indicated in Table 15-3.

TABLE 15-1. MALFUNCTION INDICATIONS, TANK TURRET DRIVE

Abnormal Noise in Hydraulic Pump or Motor		Hydraulic Motor and Pump Operates, Turret Fails to Traverse				Turret Traversing Speed Slow or Erratic			Manual Elevating System Inoperative or Slow			Fault or Symptom
Low Reservoir Oil Level	Power Pack Drive Motor Overheats or Burned Out	Turret Traverse Lock or Gun Traverse Lock Not Released	Defective Traversing Gear Box	Faulty Magnetic Brake Switch	Defective Pin Lock	Main Pinions or Turret Ring Gear Excessively Dirty	Hull Turret Seal Inflated	Low Reservoir Oil Level	Restriction in Hydraulic Lines	Air in Manual Elevating System	Hand Pump Accumulator Low Pressure in Elevating	1. Tank Turret Drive Measurement / Malfunction
L, N	N	N	N	N	N	N	N	N	L	L	L	Hand Pump Accumulator Oil Press.
L	N	H	N	N	N	N	N	L	N	N	L	Reservoir Oil Level
L	H	N	N	N	N	N	N	L	N	N	L	Power Pack Drive Motor Current
H	N	N	N	N	N	N	N	N	N	N	N	Oil Temperature
L	L	N	N	N	N	N	N	L, N	N	N	N	Accumulator Nitrogen Pressure
H	N	N	N	N	N	N	N	H	N	L	N	Accumulator Hydraulic Pressure
L	N	N	N	N	N	N	N	N	N	N	L	Hydraulic Oil Leaks
H	N	N	N	N	N	N	N	N	N	L	N	Manual Accumulator Nitrogen Press.

TABLE 15-2. MALFUNCTION INDICATIONS, HOWITZER RECOIL MECHANISMS

Hydraulic Fuel Level Cannot be Maintained in Recoil Mechanism			Barrel Does Not Return Completely to Battery	Barrel Returns to Battery with Too Great A Shock			Fault or Symptom
Replenisher Piston and/or Seals Damaged	Damaged or Defective Recoil Sleeve	Leaks In Recoil Mechanism Follower Seal Assemblies	Weak or Defective Recoil Mechanism Spring	Counterrecoil Buffer Piston Vibrated Loose From Threaded Shaft and/or Damager Retainer Seals	Low Pressure in Recoil System - Leakage	Excessive Recoil Mechanism Spring Tension	1. Howitzer Recoil Mechanism Measurement / Malfunction
N	N	N	L, N	N	N	H	Recoil Mech. Spring Tension
L, N	L, N	L, N	L	N	L, N	N	Recoil System Pressure
N	N	N	L	L	N	N	Counterrecoil Spring Tension

TABLE 15-3. MALFUNCTION INDICATIONS, FULL-TRACKED TRACTOR

Brakes Will Not Apply			Brakes Dragging or Running Hot	Sluggish Steering	Sluggish Operation		Transmission and Torque Converter Overheat				Drive Train Fault or Symptom
Expander Tube Nozzle Packing Leak	Supply Line Leak	Air in Hydraulic System	Air in Hydraulic Actuating System	Low Hydraulic Pressure	Low Oil Pressure	Low Oil Level	Excessively High Engine Temperature	Low Transmission Oil Level	High Range Repeatedly starting from Standstill in	Operating in too High Speed Range	Transmission Hydraulic System / Steering Brakes — Measurement — Malfunction
N	N	N	N	N	N	N	H	N	H	H	Engine Coolant Temperature
N	N	N	N	N	N	N	H	N	H	H	Engine Lube Oil Temperature
N	N	N	N	N	N	H	L	L	H	L	Torque Converter Oil Temperature
N	N	N	N	N	N	L	H	L	H	L	Torque Converter Oil Pressure
N	N	N	N	N	N	H	H	H	H	H	Transmission Oil Level
N	L	N	N	N	L	N	N	N	N	H	Transmission Oil Temperature
L	L	N	N	L	N	N	N	N	N	L	Hydraulic System Oil Level
L	N	L	N	L	N	L	L	L	L	L	Hydraulic System Oil Filter Δ Pressure
N	L	L	N	L	N	N	L	N	L	L	Transmission Oil Filter Δ Pressure
N	L	N	L	L	N	N	L	N	L	N	Engine Driven Pump Pressure
N	L	L	L	L	N	N	L	N	L	N	Engine Driven Pump, Relief Valve Δ Pressure
N	N	N	L	L	N	N	H	N	H	H	Hydraulic System Oil Temperature
N	N	N	L	L	N	N	N	N	N	N	Main Hydraulic Pump, Front Section Pressure
N	N	N	L	L	N	N	N	N	N	N	Main Hydraulic Pump, Rear Section Pressure
N	N	N	L	L	N	N	N	N	N	N	Lift Cylinder Pressure
N	N	N	L	L	N	N	N	N	N	N	Side Shift Cylinder Pressure
N	N	N	L	L	N	N	N	N	N	N	Extension Cylinder Pressure
N	N	N	L	L	N	N	N	N	N	N	Tilt Cylinder Pressure
N	N	N	L	L	N	N	N	N	N	N	Oscillate Cylinder Pressure
N	N	N	L	L	N	N	N	N	N	N	Steering Cylinder Pressure
N	N	N	N	N	L	L	L	L	L	N	Transmission Output Speed, rpm
L	L	L	L	L	L	L	L	L	L	L	Accumulator Pressure

TABLE 15-4. CANDIDATE TEST POINTS, TRACTOR/ROAD GRADER

1.	Filter return line pressure tap
2.	Dozer pump exit pressure tap
3.	Blade hydraulic cylinder feed and return lines pressure taps
4.	Tilt cylinder feed and return lines pressure taps
5.	Blow, apron, ejector lock and quick drop feed and common return line pressure taps
6.	Steering pump single entry and double output pressure taps
7.	Steering cylinders feed and return line pressure taps
8.	Oil cooler Δ_T temperature taps
9.	Transmission hydraulic pump single entry and double output pressure taps
10.	Transmission oil filter Δ_P pressure taps
11.	Oil cooler Δ_T temperature taps
12.	Torque converter to transfer case pressure tap
13.	Transmission clutch pressure taps

CHAPTER 16
AIRBORNE HYDRAULIC SYSTEMS

16-1 GENERAL

Hydraulic systems in airborne vehicles are oriented primarily toward flight control functions. Hydraulics generally provide full power capability plus stability augmentation, allowing low control system force levels while also providing good flight characteristics. Meeting design requirements for handling qualities without stability augmentation can be very difficult if not impossible. If the vehicle has a stability margin without augmentation and also has relatively low control peak load requirements, power boost with manual reversion may be used. The force levels required after reversion to the manual mode should be such that a pilot can continue flight for a reasonable period prior to landing without excessive physical discomfort.

Utility functions that require or can use hydraulics are varied. Hydraulic systems are used to provide power and control for hoist or winch systems. Doors and loading ramps can use hydraulics as the optimum approach. The landing gear, when retractable, requires hydraulics. Other utility applications include gun turrets and gun drives, wheel braking and steering, rotor braking, fluid dampers and cargo hooks.

The engine starting system is an important application for hydraulics. Self-contained, independent engine starting can be provided through the use of a hand pump and accumulator system. The starting motor sometimes is designed to be convertible to a hydraulic pump after starting.

16-2 TEST REQUIREMENTS FOR A HELICOPTER HYDRAULIC SYSTEM

Figure 16-1 shows a typical system schematic setup for the testing of a helicopter hydraulic system with pressure and temperature monitoring points included. Temperature-monitoring capability should be incorporated at the:

(1) Pump outlet
(2) Pump case drain outlet
(3) Pump suction

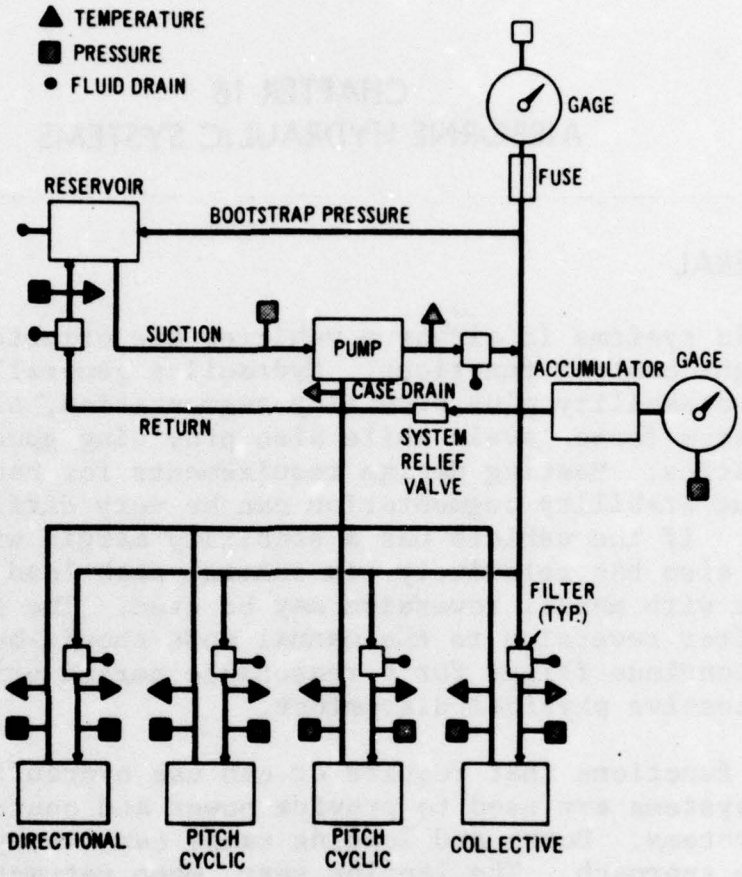

Figure 16-1. System Setup and Instrumentation

(4) Reservoir return
(5) Actuator supply
(6) Actuator return

Other temperature sensing locations may be desirable, especially if a system heat exchanger is required as part of the system design.

Pressure transducers should be provided at appropriate circuit locations. It is desirable to avoid major changes in system plumbing. Key points for monitoring pressure include:

(1) Reservoir bootstrap pressure
(2) Reservoir return

(3) Pump suction
(4) Pump outlet
(5) Branch circuit supply at using component
(6) Branch circuit return at using component
(7) Accumulator charge.

Installation of flowmeters as a part of the original setup may be difficult because they must be in-line and hence are added restrictions. Also, different flowmeters may be required at a single location because of variations of flow rate in different test sequences. Flowmeters, therefore, are best utilized as required - incorporated at specific points and removed as demanded by the test objectives.

16-3 APPLICATION OF ATE MEASUREMENT PRINCIPLES TO A FLIGHT CONTROL HYDRAULIC SYSTEM

As an example of the application of ATE to an airborne vehicle, the flight control hydraulic system for a UH-1H helicopter has been chosen (Reference 1). The system is shown in Figure 16-2. In this example, a provision has been made by the designers of the hydraulic system for system operation using an external hydraulic supply. However, because they have not utilized the return line relief valve, (feature E in Figure 15-1) it is necessary to disconnect the main return line and couple it to the external supply. The high pressure line needs only to be connected to the external supply, since a check valve has been provided to avoid backdriving the aircraft pump.

The features of the ATE-equipped hydraulic flight control are:

(1) Pump discharge measurement. This orifice is included to allow a measurement of pump flow using a sensitive (5 psi) differential pressure transducer connected to the taps provided. The orifice is sized to yield a 4 psi drop at maximum flow. In this manner, pump flow at operating pressure may be determined, and so the condition of the pump relative to internal leakage may be discovered. Discharge pressure is measured simultaneously with flow by a separate pressure transducer.

(2) Actuator flow measurement. In a manner similar to that used for the pump, flow-measuring orifices are provided at each actuator, allowing simultaneous flow and pressure measurement during actuator exercise. Catastrophic leakage, either within the servo valve or across the actuator seals, should be manifest in these measurements. Low levels of seal leakage cannot be detected by these measurements because the levels of differential pressure are too low to be detected. One must fall back on the traditional technique of blocking both cylinder lines and then loading the cylinder with a force that will cause it to creep if leakage exists.

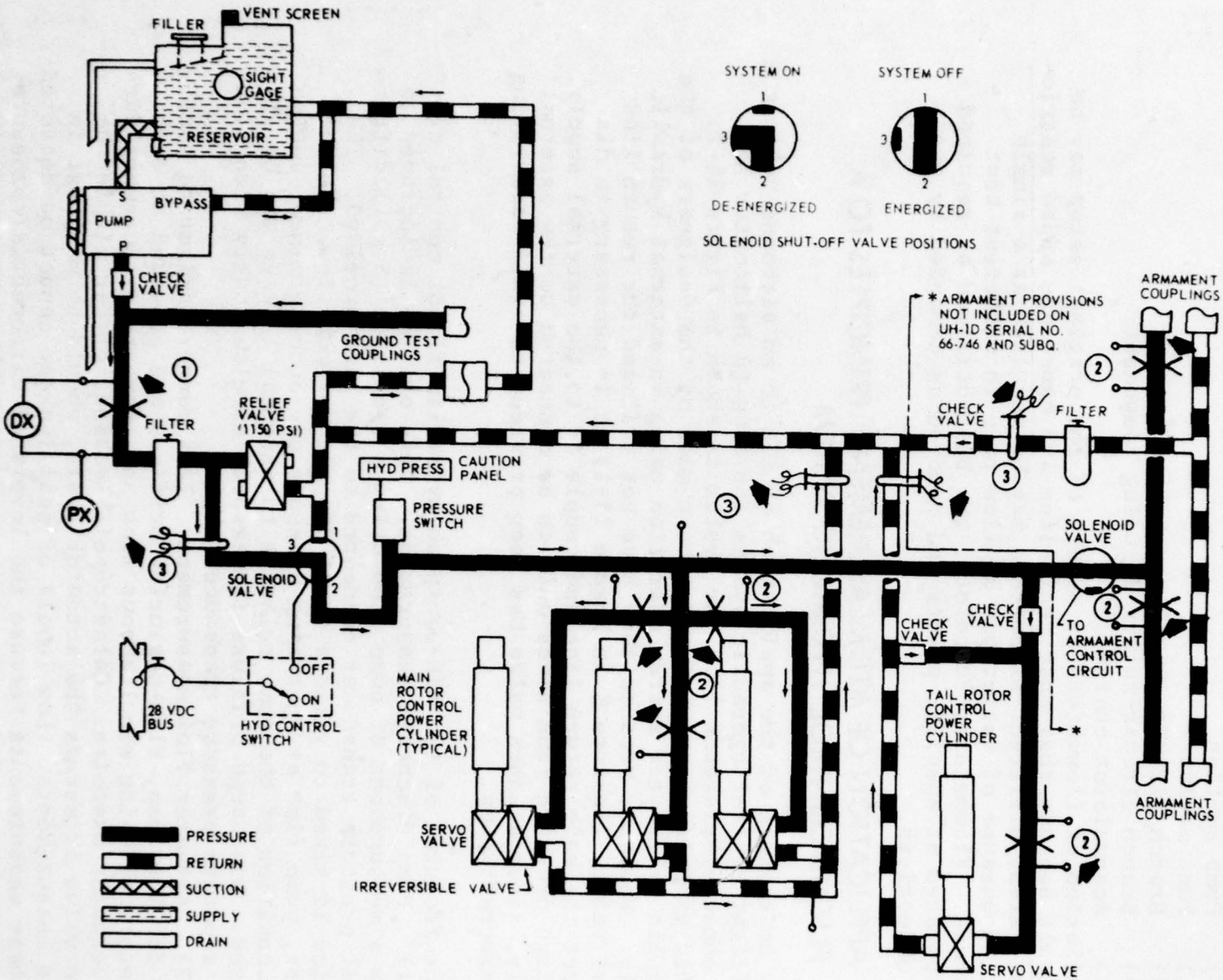

Figure 16-2. UH-1H Flight Controls Hydraulic System (ATE Modified)

(3) Temperature probe. One supply and three return line temperature probes are included. They would typically be of the thermistor class of resistance-temperature-device (RTD), but one or more could be, for highest accuracy, a platimum RTD.

16-4 CANDIDATE TEST POINT PARAMETERS

Tables 16-1, 16-2 and 16-3 present a list of candidate test points for the hydraulic systems in two aircraft. In general, Δ_p taps require a differential pressure transducer as a means of determining the quality of a filter element. Other pressure taps are single-ended. Additionally, various solenoid current taps are suggested to verify the presence of electrical power.

16-5 MALFUNCTIONS

Table 16-4 lists common malfunctions and indications of malfunctions for two different helicopter hydraulic controls. This table lists most malfunctions associated with the helicopters. Certain malfunctions and/or malfunction indications may not be applicable to a specific design, hence should not be included in the checklist for the particular helicopter. The measured values of each parameter are listed as N (normal), H (high) and L (low). Measured values for a parameter must be verified against the specific values and tolerances for a particular model to determine whether they are normal, high or low.

Where automatic test equipment or automatic data processing is used for complete fault diagnosis, it may be desirable to program all applicable malfunction indications in order to obtain as complete a diagnosis as possible. However, where diagnosis is performed manually, using tables from a handbook, only the three or four most prominent symptoms should be indicated to minimize the burden of data collection and comparison by the repairman. This is generally sufficient as any malfunction affecting the parts of the helicopter control system requires disassembly and the specific failed part can then be determined by visual or instrument-aided inspection.

TABLE 16-1. CANDIDATE TEST POINT LOCATION AND PARAMETERS, AIRCRAFT FLIGHT CONTROL HYDRAULIC SYSTEMS

1.	Hydraulic reservoir tank pressure and level taps
2.	Hydraulic pump input and output pressure taps
3.	Filter Δ_p taps (pump to three way solenoid valve)
4.	Solenoid valve pressure taps and current taps
5.	Solenoid valve to dual boost actuators - filter Δ_p pressure tap
6.	Supply line to SAS extendable links filter and reducer pressure-drop taps
7.	Supply line to stick boost actuator filter and reducer pressure-drop taps
8.	Gas solenoid valve current tap
9.	Hydraulic pump output pressure tap
10.	Main filter Δ_p taps
11.	Main rotor control cylinders servo valve exit pressure tap
12.	Tail rotor control cylinder servo value exit pressure tap
13.	Armament line filter Δ_p taps
14.	System solenoid and armament solenoid current taps

TABLE 16-2. CANDIDATE TEST POINT LOCATION AND PARAMETERS, AIRCRAFT UTILITY AND ENGINE STARTING HYDRAULIC SYSTEM

1.	APU start valve pressure tap (accumulator side) and current tap
2.	APU motor/pump output and return pressure tap
3.	Engine start valve external pressure tap (both engines)
4.	Utility pump/dual compensator output pressure tap
5.	Utility pump/dual compensator control valve current tap
6.	Utility pump to accumulator line filter and pressure reducer Δ_p taps
7.	Oil cooler fan motor input pressure tap
8.	Fan motor control valve current tap
9.	Oil cooler Δ_t taps
10.	AGB motor valve current tap
11.	Utility system valve exit pressure tap
12.	Utility system valve current tap
13.	Manifold thermal switch current tap
14.	Utility pump control valve current tap
15.	Engine start valve current tap
16.	Return line to pressure tank filter Δ_p tap

TABLE 16-3. CANDIDATE TEST POINT LOCATION AND PARAMETERS, AIRCRAFT STEERING, BRAKES, CARGO HOIST AND RAMP HYDRAULIC SYSTEM

1. Wheel brake supply line pressure tap
2. Hoist control valve pressure tap
3. Hoist control valve current tap
4. Hoist brake release solenoid valve current tap
5. Cargo hook solenoid valve current tap
6. Aft wheel brake solenoid valve current tap
7. Power steering solenoid valve current tap
8. Swivel lock solenoid valve current tap
9. Ramp actuator delivery and return pressure taps

TABLE 16-4. HYDRAULIC HELICOPTER CONTROL MALFUNCTIONS.

Leaks In System	High Frequency Vibration In Aft Transmission Area	High System Pressure	Low System Pressure		Hydraulic Oil Overheating				Excessive Control Vibration	Low System Pressure	Hydraulic Controls Fault or Symptom
Defective Seals, Packing, Lines	Defective Pump	Defective Compensator Action	Broken Pump Compensator Spring, Sticking Spool Valve	2. CH-47B/C	Relief Valve Stuck Open	Leaks in Lines, Seals, Gaskets	Low Oil Level	Damaged Pump	Irreversible Valve Chatter	Controls Sluggish	1. UH-1D/H Measurement Malfunction
L	N	N/M	N/L		H	L	L	N	N	N/L	Hydraulic Reservoir Oil Level
					H	N/M	N/M	H	N	H/L	Hydraulic Reservoir Oil Temp.
N/L	N	N/H	L		N	L	N/L	L	N	N/L	Hydraulic Pump Inlet Pressure
N/L	N/H	H	N/L		N	N/L	N/L	N/L	N	N/M	Hydraulic Pump Outlet Pressure
N/L	N/H	H	N		N	N	N	N/L	N	N/M	Hydraulic Pump Ripple
N/M	N/H	N	L		N	L	L	L	N	N/L	Hydraulic Pump Speed, RPM
	L	H			L	N/L	N/L	L	N	N/L	Hydraulic Pump Filter Δ Press.
					N	N	N/L	L	N/H	H/L	Main Rotor Control Cylin. Δ Press.
					L	N/L	N/L	L	H/L	H/L	Tail Rotor Control Cylin. Δ Press.
					L	L	N/L	L	H/L	N/L	Irreversible Valve Δ Pressure
					H	H	N/L	L	N	L	Pressure Relief Valve Δ Pressure
											Hydraulic Pump Flow
N/L	N	N/M	N/M								Hydraulic Reservoir Oil Pressure
N/M	H	N/M	N/M								Hydraulic System Oil Temperature

REFERENCES

1. TM 55-1520-210-20, Organizational Maintenance Manual, Army Model UH-1 D/H Helicopter, Department of the Army, 10 September 1971.

CHAPTER 17
GAS TURBINE ENGINES

17-1 GENERAL

Monitoring systems for gas turbines are potentially capable of detecting incipient failures, providing a state-of-health indication as well as collecting and storing data for later in-depth analysis. The advent of reliable low cost computers has permitted the design of on-engine monitoring systems which are capable of analyzing engine performance and condition on the basis of measured and computed parameter values. However, the capability of the computer-based monitoring system poses a number of difficult design problems. For example, what analytical procedures are appropriate? What data is to be committed to storage? How is the presence of abnormalities to be communicated to the engine operator? How accurately must parameters be measured? and how frequently must measurement samples be taken?

A consideration of the impact of a monitoring system on the design of an engine can only be made after the objectives of the system have been identified and a design concept has been formulated on the basis of these objectives.

It is important that the system concept be formulated during the engine design stage so that any essential requirements for mounting transducers to the engine can be accommodated. Although retrofit of an existing engine is possible, it will invariably result in restrictions in transducer placement which compromise performance.

The concept formulation of the monitoring or test system is best made by the engine designer because of his familiarity with the engine and his ability to evaluate the impact of malfunctions on both measured and computed parameters.

17-2 ADVANTAGES OF AN ENGINE MONITORING OR TEST SYSTEM

The following list itemizes some objectives which could be consequential in deriving design concepts:

(1) Diagnosis of mechanical malfunctions

(2) Warning of impending failure
(3) Eliminate unnecessary inspections
(4) Eliminate unnecessary part removal
(5) Eliminate changing parts on basis of time rather than condition
(6) Minimize spare parts inventory
(7) Reduce life cycle engine ownership costs
(8) Increase availability
(9) Increase probability for mission success
(10) Improve safety
(11) Provide engine health status at any time, location, and environment
(12) Extend time between overhaul
(13) Record-keeping ability
(14) Monitor Specific Fuel Consumption
(15) Indicate thrust deficiency
(16) Give real time information on engine health status; reduce operational work load
(17) Give maintenance crew definitive maintenance items; fault isolation
(18) Provide GO/NO GO for military engines which have severe abnormal usage
(19) Evaluate impact of, excursions into forbidden operating region

17-3 DETECTABLE PROBLEMS

Achieving the functional objectives of the system ultimately involves the ability to detect malfunctions and abnormalities in the engine. Current monitoring and test systems are successful in detecting such problems as those in the following list:

(1) Crank Time Limit Exceedance
(2) Starter Spline Sheared
(3) GTC Problem
(4) N_1 Friction Problem
(5) No Fuel
(6) Ignition Problems
(7) Hot Section Distress
(8) Hot Start
(9) Hung Start
(10) Bad Thermocouples
(11) Oil Flow Low
(12) Oil Flow High
(13) Idle Trim Low
(14) Idle Trim High
(15) Fuel Pressure High
(16) Vibrational Problems

(17) Foreign Object Damage
(18) Oil Pressure Low
(19) Oil Temperature High
(20) Dirty Oil
(21) Metal in Oil
(22) Deficient fuel acceleration schedule
(23) Bleed control deficient
(24) Cooling air pressure out of limits
(25) Performance parameters out of limits

17-4 TYPICAL INSTRUMENTATION LOCATION

Figure 17-1 shows the typical instrumentation locations for a turbo shaft engine monitoring system.

17-5 SYSTEM IMPLEMENTATION

To implement a design which will achieve the desired system functions, the following areas must first be defined:

(1) The functions to be achieved by the monitoring or test system.
(2) The malfunctions to be detected.
(3) The parameters to be measured by transducers.
(4) The analytical and diagnostic procedures to be applied to the measured data, particularly the algorithms pertaining to gas path analysis.

The system will consist of transducers, computational hardware and diagnostic software. In considering the basic engine design, thought must be given to placement of the transducers as well as a suitable location for the hardware associated with the transducer interface and the computational equipment.

In the first instance, the system concept will lead to an idealized list of measurables. The ideal parameter is one which exhibits high sensitivity to the failure mode of interest and also is specific to only a few malfunction types so that it can be used to perform diagnosis and fault isolation. However, it is recognized that all ideal parameters are not necessarily accessible as inputs to a test or monitoring system. This may be due to lack of availability of a transducer or inaccessibility of the required mounting location. A typical example of this is the lack of availability of a reliable transducer for continuous measurement of turbine inlet temperature.

In any practical system quantities measured are a compromise, and not all the ideal parameters for fault detection and isolation are accessible, and this frequently results in an additional

burden on the analytical portion of the system which must attempt to perform accurate diagnosis on the basis of input data which is less than optimum.

17-6 INTERNAL INSPECTION PROVISIONS

Internal inspection of the engine gas path using a flexible fibre optic system referred to as a Borescope is an important engine evaluation technique. The flexibility of the device enables it to be inserted through ports in the engine to permit visual inspection of such inaccessible engine components as fuel nozzles, combustion liners and turbine blades and vanes.

The FT9 Marine gas turbine (Marine version of the JT9D, Ref 1.) is, for example, supplied with some twenty borescope inspection ports The FT9 Marine gas turbine engine is a 33,000 horsepower version of the Pratt and Whitney JT9D engine, which powers the 747 aircraft. In the case of the marine turbine, borescope inspections are particularly important because compressor performance is subject to deterioration due to sea salt accumulations on compressor blading.

17-7 MODULAR CONSTRUCTION

An example of gas turbine modular construction is provided by the Navy's FT9 Marine gas turbine engine development program (Ref 1.) The design incorporates the modular replacement concept. Modular replacement permits replacement of short-life components such as the hot-section without removing the engine from its mounts. The FT9 engine is built in 11 modular sections as illustrated in Figure 17-2 to facilitate onboard maintenance. There are five prebalanced rotor and stator modules, four structural case modular sections and two gearbox modules. The dimensions and weights of the modules are summarized in Table 17-1. The length of the transition duct between the gas generator turbine exit and the power turbine was sized to permit access to the interior engine modules without disturbing the engine mounting. Removal of the hot-section is illustrated in Figure 17-3. The FT9 modular construction is particularly well-suited to the on-condition maintenance concept being developed in the FT9 program.

There are several significant advantages which accrue from the modular construction concept. Basically, the number of engine removals for maintenance is drastically reduced. Defective components can be readily removed, and a prebalanced replacement

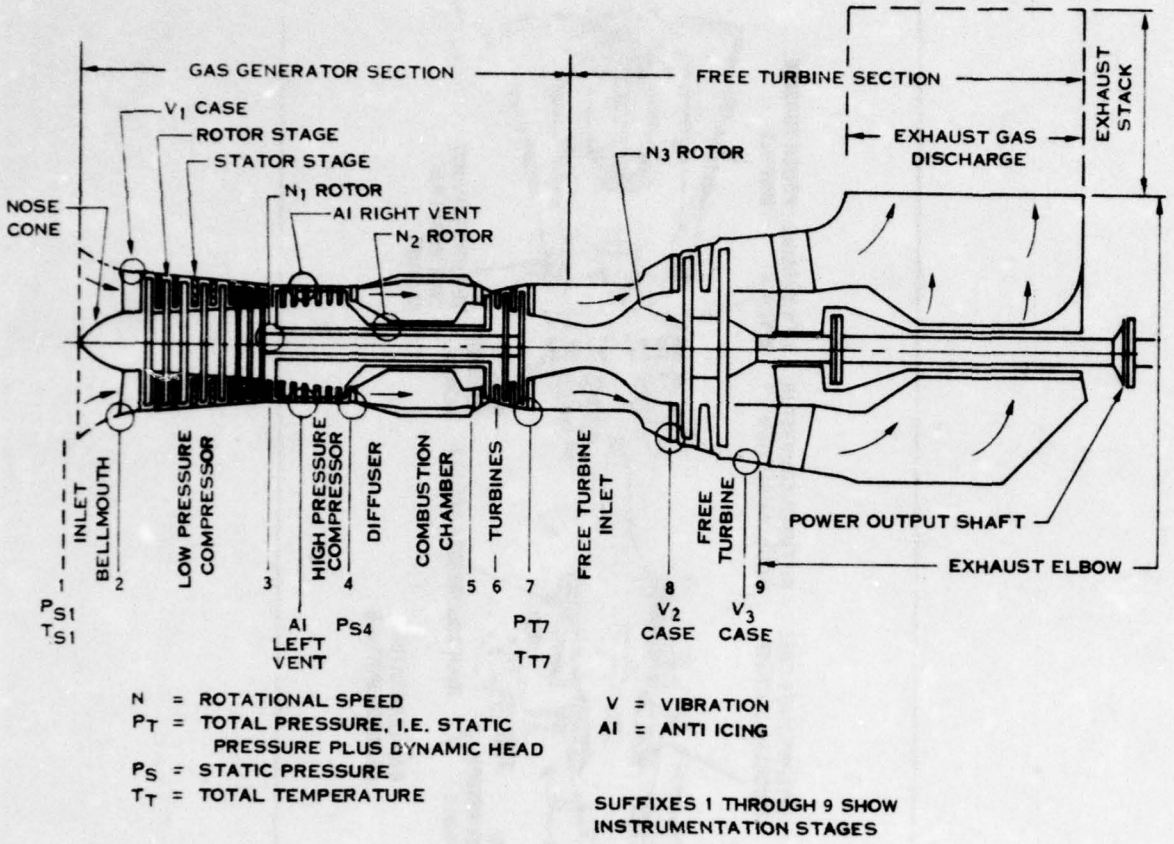

Figure 17-1. Typical Instrumentation Locations

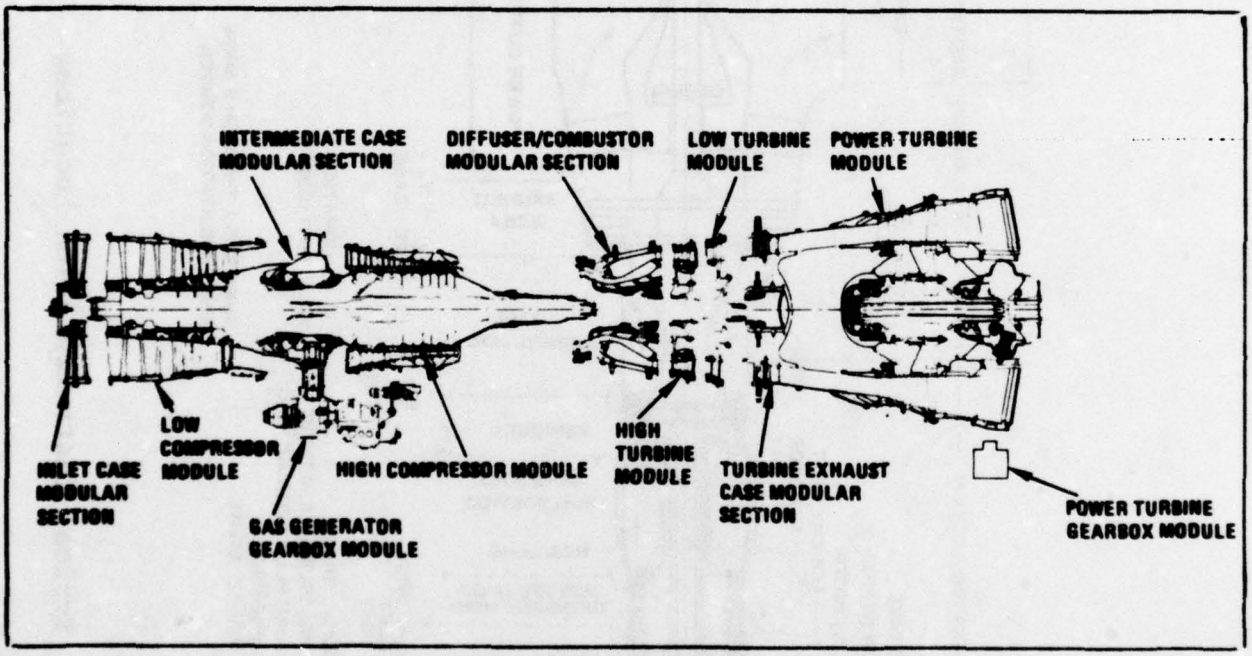

Figure 17-2. FT9 Modular Construction

TABLE 17-1. SUMMARY OF FT9A MODULAR WEIGHTS AND SIZES

MODULE	APPROX. WEIGHT (POUNDS)	APPROX. SIZE (INCHES) DIAMETER	LENGTH
INLET CASE	410	45	8
LOW PRESSURE COMPRESSOR	2203	45	52
COMPRESSOR INTERMEDIATE CASE	1298	44	21
GAS GENERATOR GEARBOX	155	26	8.5
GAS GENERATOR ACCESSORIES	670	–	–
HIGH PRESSURE COMPRESSOR	1119	38	76
COMBUSTOR	853	43	33
HIGH PRESSURE TURBINE	929	45	12
LOW PRESSURE TURBINE	800	48	12
TURBINE INTERMEDIATE CASE	820	49	20
LOW ROTOR SHAFT	333	8	88
HIGH ROTOR SHAFT	172	10	34
GAS GENERATOR TOTAL	9762		
POWER TURBINE (WITH INLET DUCTS AND SHAFT)	9425	74	60
POWER TURBINE EXHAUST DUCT (RECTANGULAR)	1025	90 W	47 L 77 H
POWER TURBINE GEARBOX AND ACCESSORIES	240	22	12
POWER TURBINE TOTAL	10,690		
RADIAL INLET (ENGINE MOUNTED COMPONENTS)	185	86	21
PIPING, ETC., NOT ASSOCIATED WITH A PARTICULAR MODULE	663	–	–
GRAND TOTAL FOR FT9A	21,300		

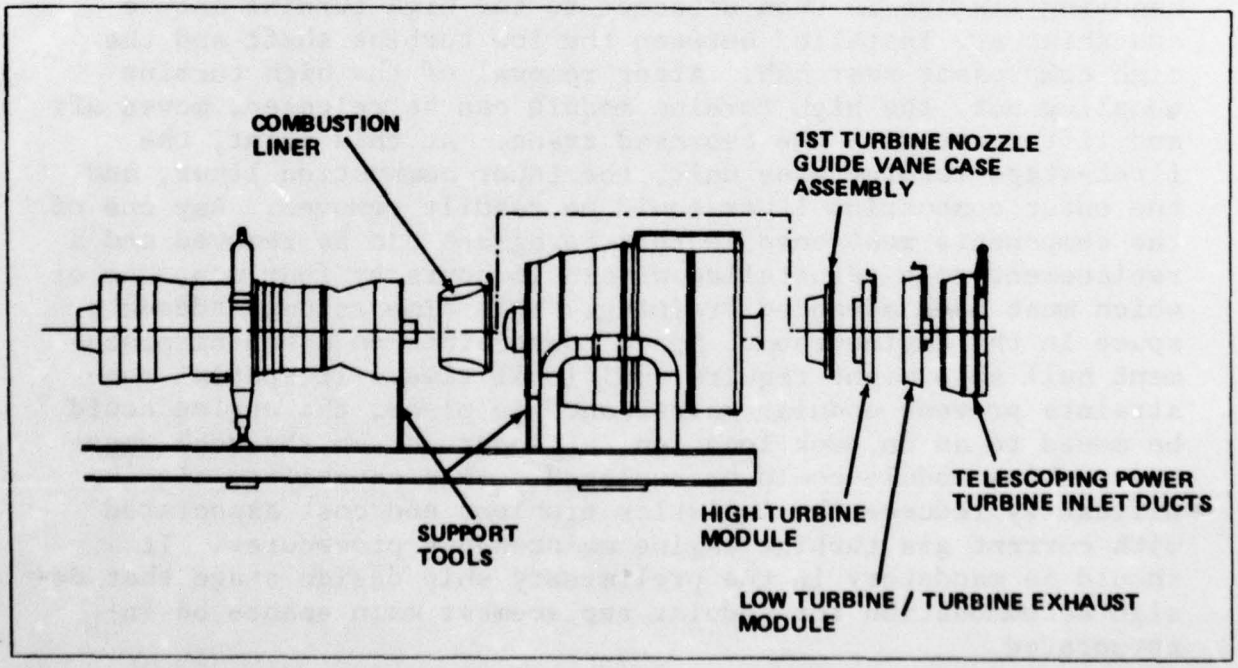

Figure 17-3. Section Parts Replacement with Modular Concept

module can be installed, effecting rapid repair. Thus, the logistics cost will be greatly reduced as provisioning of modules reflecting module lifetime can be effected rather than complete engines where any one component could life limit the engine.

The extent of Ship's Force capability to repair engines by replacing modules has not been fully defined. Repair procedures will vary for ship types, particularly between conventional and non-displacement hull craft. At least in the initial introductory stages, Ship's Force personnel will be augmented by shore side or Tender personnel for engine repair. The time between engine removals for depot level maintenance on the complete engine will be much longer than with any other naval engine.

The modular replacement concept can be illustrated with the high turbine removal procedure shown in Figure 17-3. Alternate gas generator and power turbine supports are installed first. The center and aft flange bolts are removed and the power turbine inlet case is telescoped forward. The inner duct is disconnected from the engine, attached to the power turbine inlet case, and this unit is then removed with an overhead crane. The low turbine module, including the Number 5 bearing, the low turbine rotor, low turbine case and turbine exhaust case are removed next. A handling fixture is then attached to the high turbine module and shims are installed between the low turbine shaft and the high compressor rear hub. After removal of the high turbine coupling nut, the high turbine module can be released, moved aft and lifted out with the overhead crane. At this point, the first-stage turbine vane unit, the inner combustion liner, and the outer combustion liner could be readily removed. Any one of the components mentioned in this paragraph can be removed and a replacement unit reinstalled within 16 hours by four men, one of which must have advanced training. This time assumes adequate space in the engine room. Space constraints on a non-displacement hull ship might require additional time. If spatial constraints prevent modular maintenance in place, the engine could be moved to an on deck location, a Tender, or on the dock where the problem module could be replaced. This capability significantly reduces the logistics problems and cost associated with current gas turbine engine maintenance procedures. It should be mandatory in the preliminary ship design stage that design accommodation for modular replacement maintenance be incorporated.

17-8 INSTRUMENTATION SPECIFICATION AND ENVIRONMENT

Detection of faulty sensors is a prime requirement for a turbine monitoring system. Consideration should be given to built in devices for checking individual transducers as well as system concepts for cross checking between parameter values computed from different transducer inputs. Life time of the instrumentation is important and the following considerations should be given to the specification of a transducer:

(1) Operating temperature range
(2) Operating pressure range
(3) Vibration levels
(4) Acoustic environment
(5) Accuracy
(6) Lifetime (false alarms)
(7) Response rates
(8) Volume
(9) Weight
(10) Electrical interface
(11) Electromagnetic interference
(12) Calibration requirements
(13) Maintenance requirements
(14) Repeatability

Many of the specifications relate to the operating environment for the sensor. Sensors for engines usually are exposed to oil mists. The temperature environment is severe with instruments being exposed to soak down temperatures. Acoustic and vibration levels are high. The relative location of signal conditioning equipment is important. One would like to put the equipment in a milder environment than that experienced by the sensors. This may require long leads which are not desirable. Optical instruments, e.g., pyrometers, have problems with windows.

17-9 GAS PATH ANALYSIS

The function of the turbine engine is to develop horsepower either as thrust or as rotational energy at the output drive shaft. This energy is derived from the expansion of high pressure high temperature gases at the turbine nozzle. Computations made on gas path parameters yield information about the power being developed by the engine.

By measuring flow quantities upstream and downstream of each component, information is obtained for fault isolation. Component efficiency can be calculated. Efficiency is a one-dimensional concept based on some kind of average pressure and

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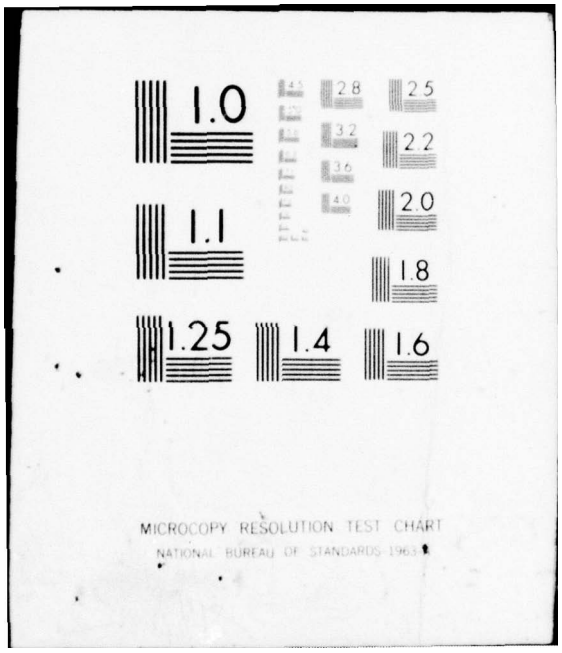
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By measuring flow quantities upstream and downstream of each component, information is obtained for fault isolation. Component efficiency can be calculated. Efficiency is a one-dimensional concept based on some kind of average pressure and

temperature. Flow asymmetries, e.g., pattern factor for a combustor, yields valuable insight to engine defects.

For a successful assessment of engine thermodynamic performance using gas path techniques, the following items should be observed:

(1) Accurate measurement of engine speeds, pressure, and temperature

(2) Accurate electronics and calculations

(3) Corrections for Reynolds number, ambient conditions, and variable geometry

(4) Use engine signatures rather than average operating line

(5) Establish a standard set of altitudes and power settings for data repeatability

The objective of performance monitoring through gas path analysis is to detect degradations in the aerothermodynamic performance of the power plant (Ref. 2). A further objective is to determine which of the major components of the unit are at fault. The major components are the compressor, the combustor, the gas producer turbine and the power turbine. The best measures of individual component performances are efficiencies which, when compared to nominal values, will bring to light any degradations. Unfortunately, these efficiencies cannot be measured directly when the power plant is in service and the problem, then, becomes one of deducing the efficiencies of unmeasureable parameters from performance values which can be measured. A complete set of measurements involves measuring the thermodynamic state ahead and behind each of the major power plant components, (pressures and temperatures) gas flow and fuel flow, gas producer and power-turbine speeds, power turbine output torque and the power required to drive the accessories. A schematic diagram, Figure 17-4, of the power plant shows where measurements are taken; an entropy-enthalpy diagram illustrates the thermodynamic changes of state. Two comments are called for at this point:

(1) It is assumed that all measured thermodynamic quantities are reduced to standard sea-level conditions, and

(2) A certain small amount of air is usually bled from intermediate compressor stages for cooling turbine blades, cooling turbine disks or shafts etc. Since this presents a slight complication, it is assumed that the amount of air bled can be neglected. It should be noted that the set of measurements given in Figure 17-4 is redundant in the sense that not all measurements are required for computation of the desired component efficiencies. However, this somewhat idealized complete set of measurements permits the most direct determination of the

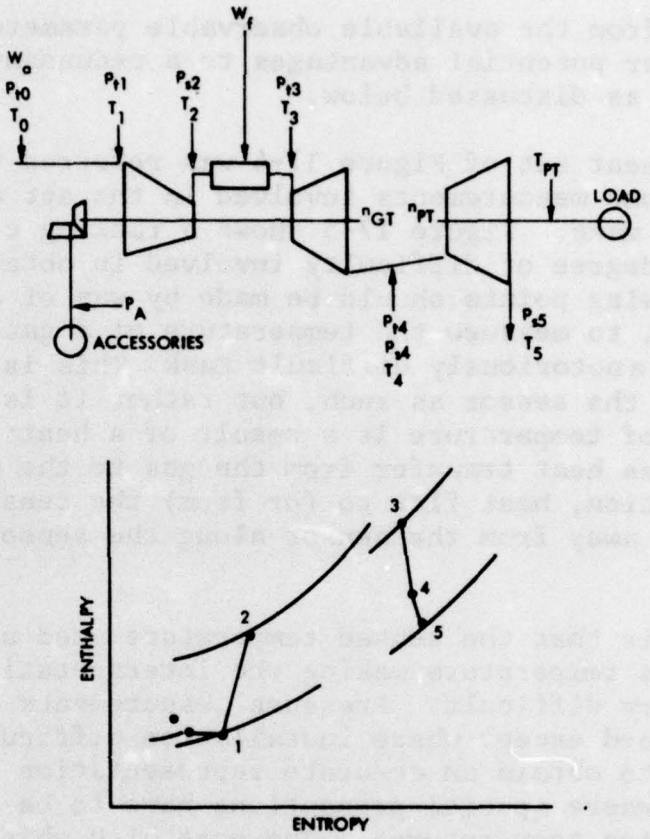

Figure 17-4. Gas Turbine Schematic Diagram

LOW	MEDIUM	HIGH
P_o	P_3	T_3
T_o	T_4	
P_1	W_a	
T_1		
P_2		
T_2		
P_4		
P_5		
T_5		
N_{GP}		
N_{PT}		
+ T_{PT}		
P_A		
W_f		

Figure 17-5. Ranking of Thermodynamic Measurements by Degree of Difficulty

efficiencies from the available observable parameters. Also, there are other potential advantages to a redundant set of measurements, as discussed below.

The measurement set of Figure 17-4 was referred to as "idealized" because some measurements involved in the set are nearly impossible to make. Figure 17-5 shows a ranking of the measurements by the degree of difficulty involved in obtaining them, and the following points should be made by way of amplification. To begin with, to measure the temperature of a gas at elevated temperature is a notoriously difficult task. This is not due to any disability in the sensor as such, but rather it is because the sensed value of temperature is a result of a heat balance; the latter involves heat transfer from the gas to the sensor by forced convection, heat flow to (or from) the sensor by radiation and heat flow away from the sensor along the sensor leads by conduction.

The result is that the sensed temperature need not represent the actual gas temperature making the interpretation of the sensor output very difficult. Pressure measurements are usually straight-forward except where installation difficulties may make it difficult to obtain an accurate representation of the desired pressure, or where special precautions have to be taken in the presence of high temperatures. The ease with which reliable air flow measurements can be made depends very much on the specific installation. If the intake to the compressor is formed by a clean bellmouth, then the drop in static pressure through the bellmouth will provide a good measure for the amount of air flow involved. In other installations, such a measure can be far more difficult to make.

Finally, the output torque of the power turbine is usually available because gas turbine control is very often achieved through a power governing system requiring this measurement as an input. Summing up, the question, as to whether all of the measurements shown in Figure 17-4 can realistically be made available, has to be evaluated on a case-by-case basis, and an affirmative answer should not be taken for granted.

17-10 HOT SECTION DETERIORATION

There are many variables which determine the life of the engine hot section. The primary variables are time, temperature and loading. Loading is due to operating pressure and for turbine components, physical rotor speed. After burners and nozzles are considered to be part of the hot section and there is need for the development of techniques and devices for failure detection in these components.

Other factors which determine hot section life are low cycle fatigue and thermal shock. Thus, hot section condition can be established by indirect monitoring of low cycle fatigue and the time integral of temperature.

Direct failure detection involves monitoring of pressures and temperatures. It has been suggested that a monitoring system should have the capability of measuring blade metal temperature with an accuracy of $\pm 15^{o}F$. This poses a significant transducer design problem.

Transducer environment and location is particularly critical in a hot section monitoring system and it is important that consideration to test and monitoring requirements be given during the engine design stage.

17-11 MECHANICAL TEST AND MONITORING TECHNIQUES

There are many engine defects which do not influence the gas path parameters. These include bad bearings and cracks in compressor discs. Vibration and sonic analysis have proved to be useful tools for detecting and isolating this type of malfunction. Typically damaged parts are detectable through their impact on the uniformity of the vibrational frequency spectrum.

Location of the transducer is of paramount importance in the successful application of the vibration technique. An accelerometer must be mounted directly on a bearing if it is to yield information about that bearing. High frequency vibrational signals are rapidly attenuated as they propogate through the engine structure and remotely located accelerometers are unable to pick up the diagnostic information.

Aeromechanical instability in the form of blade flutter can soon use all the available fatigue life. Although strain gauges are able to detect this condition, they are probably not practical for use in service monitoring of the engine. Possible

alternative techniques would include the measurement of blade clearances and again this approach would only be viable if due consideration was given to it during the engine design stage.

17-11.1 MISCELLANEOUS TECHNIQUES

Miscellaneous techniques for determining hot section deterioration include the following:

(1) In service monitoring of lube oil particulates by size and number.
(2) Off engine spectrographic oil analysis
(3) Engine rate of accelerations
(4) Engine run down time
(5) Irregularities in exhaust temperature
(6) Oil consumption

17-11.2 PROPOSED TECHNIQUES

Some techniques have been suggested as simpler alternates to current methods. These include the embedding of chemically detectable substances in bearing and other metal wearing surfaces such that the substance would be released into the lube oil after a predetermined amount of wear has taken place.

A somewhat similar approach proposes the attachment of solid substances to bearings such that an over temperature condition will cause the substance to melt and become detectable in the lube oil.

Other proposals cover the detection of minute particles in the exhaust stream as an approach to detecting rubbing blade tips.

17-11.3 EXAMPLES OF ENGINE INSTRUMENTATION

As stated earlier, it is not practical to provide specific information on all facets of engine instrumentation and the resulting impact on the engine design. So much depends upon the particular engine configuration and the goals of the test and monitoring system.

To provide an indication of typical instrumentation layouts, Tables 17-2 through 17-5 provide information on the monitoring systems used by the following:

B747 engine
CF6 engine
FT9 engine
J85 engine

TABLE 17-2. B747 MAINTENANCE RECORDER PARAMETER LIST

Parameters	Sampling Rate	Required Accuracy
Aircraft		
Engine		
Low Compressor		
• Total Discharge Pressure (P_{t3})	2/Sec	± 1%
• Total Discharge Temperature (T_{t3})	1/Sec	± 1.7°C
• Speed (N_1)	4/Sec	± 0.2%
High Compressor		
• Static Discharge Pressure (P_{s4})	2/Sec	± 1%
• Total Discharge Temperature ($T_{4.5}$)	1/Sec	± 6°C
• Speed (N_2)	4/Sec	± 0.1%
• Oil in Temperature	1/4 Sec	± 3°C
• Engine Pressure Ratio (EPR)	2/Sec	± 0.012
• Oil Breather Pressure	1/4 Sec	± 0.3 psi
• Fuel Flow	2/Sec	± 45 pph
• Oil Pressure	1/2 Sec	± 2 psig
• Exhaust Gas Temperature (EGT)	1/Sec	± 5.5°C
• Turbine Cooling Air Pressure (P_{s5})	1/4 Sec	± 1%
• Nacelle Temperature	1/4 Sec	-
• Variable Stator Angle (Beta)	1/Sec	± 1°
• Bleed Flow	1/Sec	± 7%
• Power Lever Angle (PLA)	1/2 Sec	± 1°
• Oil Quantity	1/4 Sec	± 0.5 Qt
• Engine Vibration (2 Pickups)	1/Sec	-
• Start Air Pressure	1/4 Sec	± 6 psig
Discretes		
• Squat Switch	1/Sec	-
• Fuel Heater Switch	1/4 Sec	-
• Nacelle Anti-Ice	1/Sec	-
• High Stage Bleed Valve	1/Sec	-
• Pylon Valve	1/Sec	-
• Pressure Relief	1/Sec	-
• Wing Anti-Ice Valve	1/4 Sec	-
• Pack Valve Position	1/4 Sec	-
Documentary	Entered at beginning of flight	
• Gross Weight		
• Date		
• Flight Number		
• Flight Leg		
• A/C Number		

TABLE 17-3. CF6 CONDITION MONITORING POTENTIAL CAPABILITY

Parameters	Cockpit Indication	Maintenance Recorder	Ground Checkout
BASIC ENGINE			
Engine Fuel Flow (WF)	X	X	
LP Turbine Inlet Total Temperature (EGT TT54)	X	X	
Fan Speed (N1)	X	X	
Engine Speed (N2)	X	X	
Pressure Ratio (FPR)	X	X	
Fan Discharge Pressure (P25)		X	
Compressor Discharge Temperature (Tt3)		X	
Compressor Discharge Pressure (PS3)		X	
Variable Stator Angle (Beta β)		X	
Engine Vibration (Fan) TRF	X	X	
Engine Vibration (Core) CRF	X	X	
Gearbox Vibration (2)			X
Vibration Internal No. 1 Bearing		X	
Vibration Internal No. 3 Bearing		X	
Vibration Internal No. 4 Bearing		X	
Vibration Internal No. 7 Bearing		X	
9th Stage Bleed Flow to TMF (PT9)			X
9th Stage Bleed Flow to TMF (PS9) (ΔP9 = PT9—PS9)			X
13th Stage Bleed Flow to TMF (PT13)			X
13th Stage Bleed Flow to TMF (PS13) (ΔP13 = PT13—PS13)			X
HP Recoup Flow to TMF (PTHP)			X
HP Recoup Flow to TMF (PSHP) (ΔPHP = PTHP—PSHP)			X
LP Recoup Flow to Overboard (PTLP)			X
LP Recoup Flow to Overboard (PSLP) (ΔPLP = PTLP—PSLP)			X
Power Lever Angle		X	
ENGINE LUBE SYSTEM			
Lube Oil Quantity	X	X	
Oil Pump Discharge Pressure	X	X	
Lube Oil Inlet Temperature		X	
Sumps Chip Detection (+ Master)			X
Scavenge Oil Pump Discharge Temperature	X	X	
Gearbox Pressure (Sump Reference)		X	
Sump Isolation Via Temperature (Probes in Magnetic Plug Location)		X	
Scavenge Filter ΔP	X	X	
Low Oil Pressure Switch	X		
ENGINE FUEL SYSTEM			
Fuel/Oil Heat Exchanger Fuel Discharge Temperature		X	
Engine Fuel Pump Interstage Pressure	X	X	
Fuel Tank Temperature	X	X	
Fuel Filter Clogging	X		
ENGINE STARTING AND IGNITION SYSTEM			
Ignition Exciter Voltage			X
Ignition Exciter Current			X
AIR BLEED			
Bleed Flow (Temperature Abs. P and ΔP)		X	
Inlet A/I Valve Position		X	
AMBIENT DATA			
Total Air Temperature (TTO)	X	X	
Air Speed	X	X	
Pressure Altitude (Uncorrected) (PO)	X	X	

TABLE 17-4. FT9 ON-CONDITION MONITORING PARAMETERS

Condition Monitoring Parameters	Symbol
Performance:	
Rotor Speeds—	
Low	N_1
High	N_2
Power Turbine	N_3
Temperatures—	
LPC Inlet, Plenum	Tam
LPC Discharge	T_3
HPC Discharge	T_4
HPT Exit	T_{T6}
PT Inlet	T_{T7}
PT Exhaust	T_{T9}
Pressures—	
LPC Inlet, Bellmouth, Static	P_{S2}
LPC Inlet, Bellmouth, Total	P_{T2}
LPC Discharge	P_3
HPC Discharge	P_b
Calc. LPC Ratio	P_3/P_{T2}
Calc. HPC Ratio	P_b/P_3
PT Inlet	P_{T7}
PT Exhaust	P_9
Calc. EPR	P_{T7}/P_{T2}
Miscellaneous—	
Relative Humidity, Inlet Plenum	RH
Calc. Airflow	Wa
Fuel Specific Gravity	SG_f
Fuel Temperature at Flowmeter	T_f
Fuel Flow	W_f
Stator Vane Angle	B

Condition Monitoring Parameters	Symbol
Performance:	
Miscellaneous—	
3.0 Bleed Position	3.0 BLD
3.5 Bleed Position	3.5 BLD
Calc. Fuel-Air Ratio	W_f/P_b
Calc. PT Shaft HP	HP
Time at Power	TAP
Calc. SFC	SFC
Mechanical:	
Vibration—	
Cases	
Inlet	VIB #1
Turbine	VIB #4
Power Turbine	VIB #6
Bearing	
Low Rotor Thrust	VIB #2
High Rotor Thrust	VIB #3
PT Thrust	VIB #7
Lubrication:	
Breather Pressure GG	BREP GG
PT	BREP PT
Oil Quantity	O QTY
Turbine Cooling:	
Cooling Air Supply Pressure 2nd Vane	TCASP
Cooling Air Leakage	TOBI ΔP

TABLE 17-5. J85 DIAGNOSTIC SYSTEM INSTRUMENTATION

Parameter	Sensor	Transducer/ Signal Conditioner	Span of Measurement	Accuracy* RSS (All Effects Except Temperature)	Form of the Output
P_{T2}	Pitot/Static Probe	Capacitive Pressure Transducer	23-31 inch high abs	± 0.2% Span	0-5 VDC
P_{T2} minus P_{S2}	Pitot/Static Probe	Capacitive Transducer	2.5-5.0 inch high difference	± 0.2% Span	0-5 VDC
P_{T3}	Pitot/Static Probe	Capacitive Pressure Transducer	70-120 psia	± 0.2% Span	0-5 VDC
P_{S3}	Pitot/Static Probe	Capacitive Pressure Transducer	70-120 psia	± 0.2% Span	0-5 VDC
T_{P3}	Platinum Resistance Total Temperature Sensor	Carrier Amplifier with Linearization Feedback	400-600°F	± 0.1% Span	0-5 VDC
P_{T5}	Pitot Probe	Capacitive Pressure Transducer	20-50 psia	± 0.2% Span	0-5 VDC
T_5	Chromel/Alumel T/C (Standard Product Equipment)	Solid State Thermocouple Transmitter modified for Voltage Output)	400-1400°F	± 0.4% Span	0-5 VDC
W_F	Synchro (STD Engine Production Equipment)	Transformer (Step-up)	2200-2600 pph	--	11V 400Hz 3 Phase
N	Engine Tachometer Generator (GFE)	Feed through 1 Phase of Three Phase Signal	15990-16590 RPM	No Error	24V-70Hz Maximum
A_8	Selsyn (STD Engine Production Equipment)	Unmodified	0-20% of Full Closed to Full Open	--	--
No. 2 Bearing G's	Accelerometer	Charge Amplifier	0-100 G's Average	--	Voltage
T_{amb}	Platinum Resistance Thermometer	Carrier Amplifier	+10 to +120°F	± 0.1% Span	0-5 VDC
P_{amb}	Vent to Ambient	Capacitive Pressure Transducer	23-31 inch high abs	± 0.2% Span	0-5 VDC

*Does not include probe or sensor bias error at measurement site, but does include repeatability of the probe or sensor

REFERENCES

1. Naval Engineers Journal, The FT9 Marine Gas Turbine Engine Development Program, J. W. Fairbanks, December, 1975.

2. RCA Engineer, Gas Turbine Monitoring, H. U. Burri, 1977

CHAPTER 18
PNEUMATIC SYSTEMS

18-1 GENERAL

The following general classes of pneumatic systems for which ATE may be applied illustrate the wide variance of pressure ranges involved in such testing:

(1) Industrial Controls: 0 to 50 psig -

Examples:

(a) Electro-to-pneumatic devices (remotely-controlled pressure)
(b) Hydraulic valves controlled pneumatically by diaphragm loading
(c) Air-operated actuators for butterfly, ball valves

(2) Low-Pressure Pneumatic Systems: 0 to 20 psia -

Examples:

(a) Aircraft cabin environmental control systems
(b) Air-data computers for aircraft
(c) Intake manifolds on internal combustion engines

(3) High-Pressure Pneumatic Servos: 0 to 3000 psi - Systems of this type are, for practical purposes, non-existent! (A few hot-gas servos for missiles have been designed.) Compared to hydraulic servos, the pneumatic servo's response is only (1/50) that of the hydraulic servo at supply pressures of about 1000 psig because of the effects of gas compressibility. Aside from the use as high performance servos, high pressure systems may be found providing auxiliary functions in automatic loading or handling systems for armament.

(4) High-Pressure Vehicle Systems (0 to 200 psi) - Found in military ground vehicles for:

(a) Brake actuation
(b) Air-powered accessories
(c) Horn
(d) Windshielf wipers

As an example of the application of ATE to pneumatic systems, three types of pneumatic systems (2, 3 and 4 above) are described in the following paragraphs.

18-2 TYPICAL LAND VEHICLE PNEUMATIC SYSTEM (5 TON TRUCK)

The example of Figure 18-1 is taken from the manuals of a family of Army five-ton trucks. The system is quite straightforward and is designed to provide:

(1) Power-assisted hydraulic brakes on the truck.

(2) Auxiliary air brakes on a trailer that might be towed by the truck.

(3) Accessories like the air horn and windshield wipers.

(4) Auxiliary 120psi air ports for operating impact tools, etc.

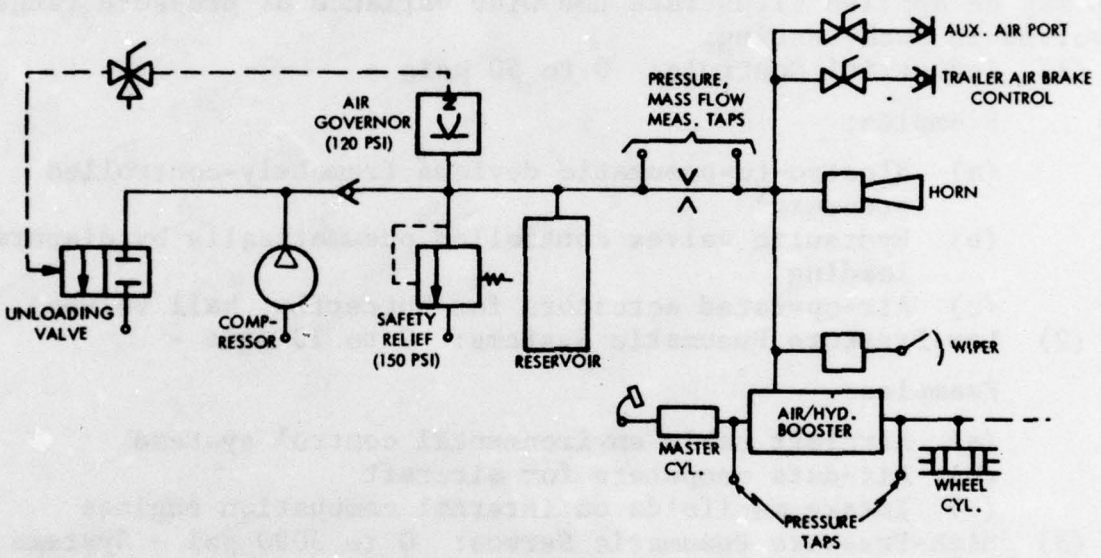

Figure 18-1. Pneumatic Subsystem - Five-Ton Truck

There are three areas of this system in which components have been introduced to aid the ATE task:

(1) A flow-measuring orifice that permits the testing of mass air flow capacity of the compressor at full pressure by bleeding air at a controlled rate from the auxiliary air port. A differential pressure transducer connected across the orifice will provide the flow measurement.

(2) A built-in manual valve in the air-governor line that will starve the unloading valve for pressure so that air pressure may be driven above the governor setting to test the relief valve. (It is possible, in some cases, that one may raise the governor setpoint above the safety relief setting and thus eliminate the need for the hand valve.

(3) Pressure taps at the input and output of the air/hydraulic booster will provide all the data needed to check the operation of the booster.

18-3 AIRBORNE COMPRESSOR - CHARGED SYSTEM

While a pneumatic system for airborne use may utilize a storage bottle precharged on the ground, a more satisfactory arrangement utilizes an airborne compressor and related components to:

(1) Filter the inlet air of particulate matter
(2) Separate free moisture and dry the air
(3) Protect the components from unsafe pressure
(4) Provide a short-term storage volume (usually a wire-wrapped accumulator so that piercing of the shell by armament will not result in a dangerous explosion).

The schematic of such a system is shown in Figure 18-2.

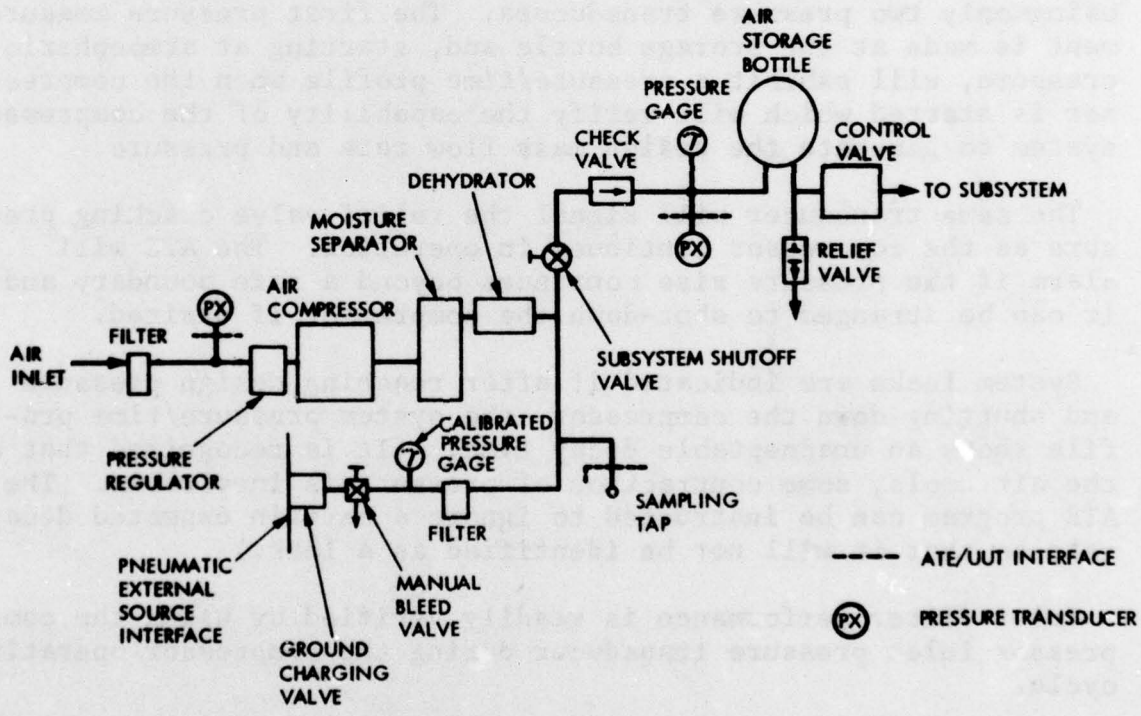

Figure 18-2. Airborne Compressor-charged System

For the purposes of automated testing, suitable pressure, temperature and mass-flow taps are required to determine, as a minimum:

(1) Compressor mass-flow capacity in the presence of operating pressure

(2) Safety relief valve operation
(3) System leaks (including internal leakage through check valves)
(4) Filter performance using pressure drop as a criterion at rated mass flow
(5) Acceptable operation of the water separator and dehydrator units. (For this purpose it is necessary to sample the output of these devices to determine the water content remaining in the air.)

Because the system shown contains an external port for charging the system with dry air during some ground testing, it is necessary that the compressor include a check valve to prevent high-pressure air from rotating it in reverse with no electrical power applied to it. Without this, a very high rotational speed can result in destroying the compressor.

The first four test objectives can be achieved in this system using only two pressure transducers. The first pressure measurement is made at the storage bottle and, starting at atmospheric pressure, will exhibit a pressure/time profile when the compressor is started which will verify the capability of the compressor system to generate the design mass flow rate and pressure.

The same transducer will signal the relief valve cracking pressure as the compressor continues in operation. The ATE will alarm if the pressure rise continues beyond a safe boundary and it can be arranged to shut-down the compressor if desired.

System leaks are indicated if after reaching design pressure and shutting down the compressor, the system pressure/time profile shows an unacceptable decay time. (It is recognized that as the air cools, some contraction of pressure is inevitable. The ATE program can be instructed to ignore a certain expected decay rate so that it will not be identified as a leak.)

Inlet filter performance is readily verified by using the compressor inlet pressure transducer during the compressor operating cycle.

Normally, a differential transducer would be used across a fluid filter, but in this case, since one side is known to be at or close to atmospheric pressure, only the filter-discharge side needs a measurement to determine filter condition.

The sampling tap at the dehydrator discharge for the purpose of measuring the remaining moisture content completes the ATE measurement interfaces which constitute a minimum test group for this system.

It is of course possible, by the addition of more pressure-transducer interface connections, to determine precisely which of the various series components are faulty but this level of diagnosis may not warrant the additional complexity needed.

18-4 VAPOR CYCLE REFRIGERATION SYSTEMS (AIRCRAFT OR VEHICLES)

The conditioning of air prior to admission to the cabin interior of an aircraft or vehicle may be accomplished by the use of a vapor-cycle refrigeration system as shown schematically in Figure 18-3. In such a system, the refrigerant is a hot liquid at high pressure at the compressor discharge port which is then cooled in the condenser and expanded to a low pressure in the receiver. This expansion causes the conversion of the liquid into a gas which results in the absorption of heat in the evaporator, thus cooling the incoming air. The heated gas is then returned to the compressor.

With the installation of suitable test ports to this system, one may expect to verify the proper operation of the equipment or diagnose faults if operation is abnormal. The test devices consist of three types:

(1) Pressure transducers
(2) Temperature probes
(3) Differential pressure transducers

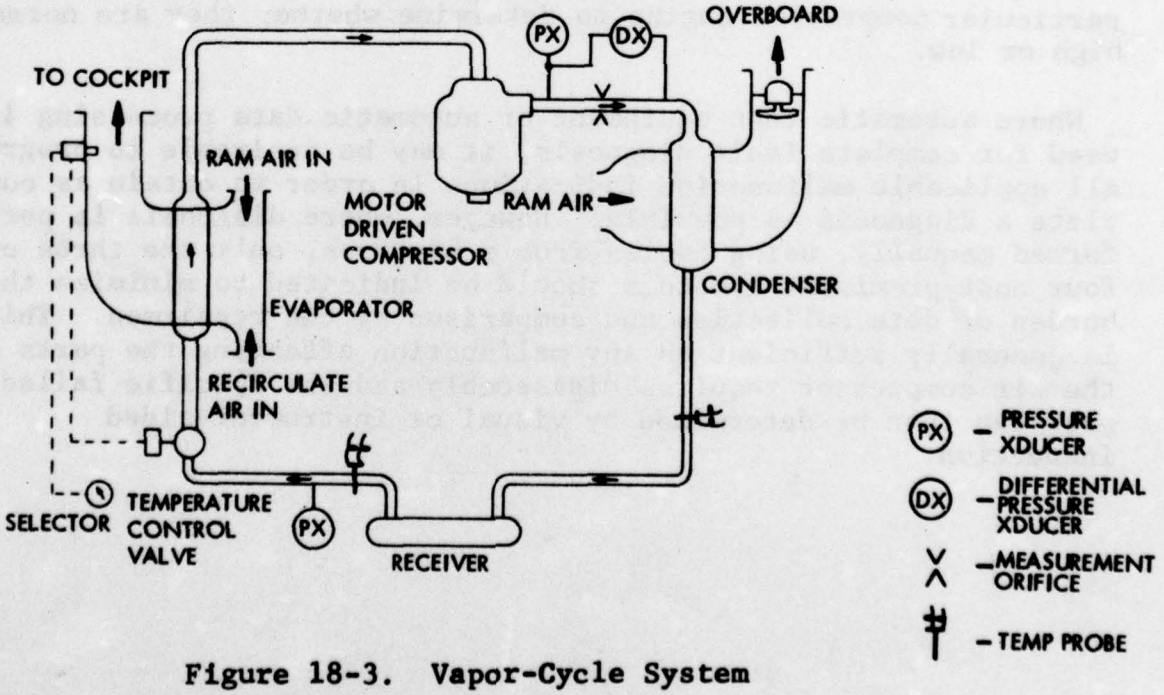

Figure 18-3. Vapor-Cycle System

The single-port pressure transducer and differential transducer shown in Figure 18-3 will confirm the fluid power delivery of the compressor by measuring the flow rate and pressure output.

The temperature probe located just downstream from the condenser establishes the quality of the heat exchange process.

Finally, the pressure and temperature probes downstream of the receiver establish the conditions in the final leg of the refrigerant loop.

Note that, because of the closed nature of the system, only a single flow rate measurement is needed to establish the steady state flow rate around the circuit and this is accomplished in the liquid portion of the circuit where it is easiest.

18-5 TYPICAL AIR COMPRESSOR MALFUNCTIONS

Table 18-1 lists common malfunctions and indications of malfunctions for an air compressor used in construction and material handling equipments. Certain malfunctions and/or malfunction indications may not be applicable to a specific design, hence, should not be included in the checklist for the particular equipment. The measured value of each parameter are listed as N (normal), H (high) and L (low). Measured values for a parameter must be verified against the specific values and tolerances for a particular compressor engine to determine whether they are normal, high or low.

Where automatic test equipment or automatic data processing is used for complete fault diagnosis, it may be desirable to program all applicable malfunction indications in order to obtain as complete a diagnosis as possible. However, where diagnosis is performed manually, using tables from a handbook, only the three or four most prominent symptoms should be indicated to minimize the burden of data collection and comparison by the repairman. This is generally sufficient as any malfunction affecting the parts of the air compressor requires disassembly and the specific failed part can then be determined by visual or instrument-aided inspection.

TABLE 18-1. MALFUNCTION INDICATIONS, AIR COMPRESSOR

Vibration	Compressor Fails to Load or Unload		Noisy Compressor Operation		Excessive Oil Consumption		Compressor Overheats					Compressor Fault or Symptom
Vanes Stuck in Rotor Slots	Line to Speed Control Damaged or Leaking	Unloading Pressure too High or too Low	Dirt on Intake Unloader Valve Seat	Loose or Damaged External Parts	Lack of Lubricant	Oil System Over-Filled	Separator Element Damaged	Dirty Oil Cooler	Blades Damaged or Stuck in Slots	Oil Separator Element Clogged	Thermal Bypass Valve Stuck	Low Oil Level in Oil Separator	Compressor Area / Measurement / Malfunction
L	H	[1]	H	N	[1]	[1]	N	N	L	L	N	N	Compressor Outlet Air Pressure
H	N	N	N	N	H	H	H	H	H	H	H	H	Compressor Oil Temperature
H	N	[1]	N	N	H	H	L	H	H	H	H	L	Oil Cooler Δ Temperature
H	L	[1]	L	N	L	L	L	H	L	H	N	L	Oil Separator Level
[1]	H	[1]	L	N	L	L	N	H	L	N	N	H	Oil Filter Δ Pressure
H	L	N	N	N	H	L	H	N	N	H	N	N	Engine Speed, rpm
L	N	[1]	N	N	L	H	N	N	L	H	N	N	Compressor Bearing Temperature
L	N	[1]	N	N	L	H	[1]	N	L	L	N	N	Compress Air Cleaner Δ Pressure
[1]	N	[1]	H	N	H	[1]	N	N	N	N	L	[1]	Oil Separator Δ Pressure
													Thermal Bypass Valve Δ Pressure

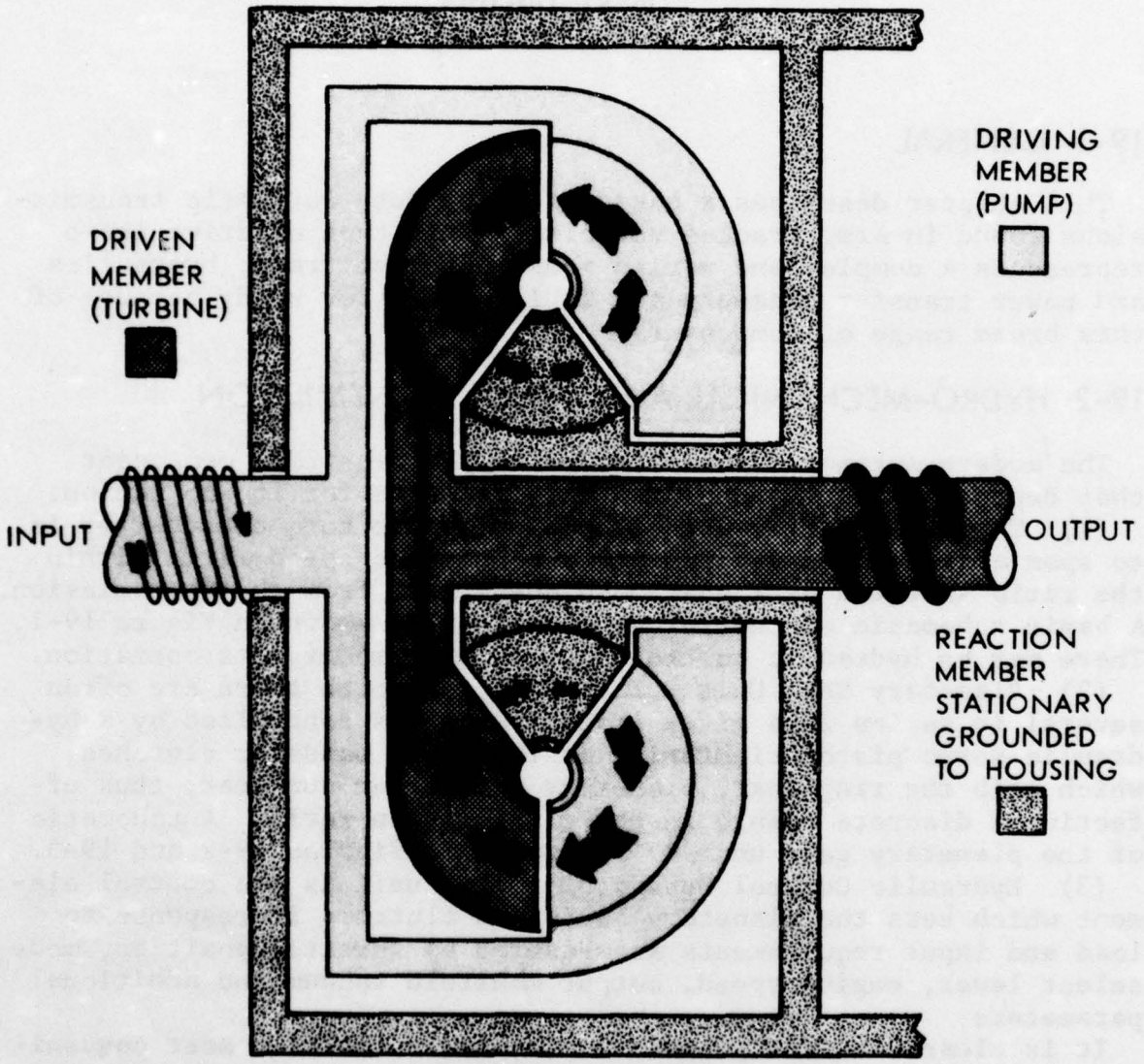

Figure 19-1. Torque Converter - Schematic Diagram

CHAPTER 19
DRIVE TRAINS

19-1 GENERAL

This chapter describes a class of heavy duty automatic transmissions found in Army tracked vehicles. This type of drive train represents a complex and varied scope of drive train, hydraulics and power transfer elements and it is chosen for study because of this broad range of components.

19-2 HYDRO-MECHANICAL AUTOMATIC TRANSMISSION

The modern automatic transmission is a drive-train component that depends primarily on three main elements for its operation:

(1) Torque Converter - The function of the torque converter is to span a speed range to provide a continuous speed ratio within the ratio selected by a gear mesh downstream from the transmission. A basic schematic of the torque converter is shown in Figure 19-1. There may be hydraulic control signals that modify its operation.

(2) Planetary Gear Unit - This unit, of which there are often several in series in a given transmission, is controlled by a hydraulic servo piston tightening or loosening bands or clutches which grip the ring gear, planetary carrier or sun gear, thus effecting a discrete change in the transmission ratio. A schematic of the planetary gear unit is presented in Figures 19-2 and 19-3.

(3) Hydraulic Control Subsystem - This unit is the control element which sets the planetary bands and clutches in response to load and input requirements as measured by throttle position, mode select lever, engine speed, output manifold vacuum and additional parameters.

It is clear that the principal parameters that are most conveniently measured in an automated test system are the pressure and temperature of the controlling hydraulic fluid signals that are supplied to the brake bands and clutches. Appropriate fluid taps brought out to external interface connectors are necessary to establish not only the cause of a catastrophic failure but, more importantly, the general condition of a major part of the transmission before such failures occur. It is clear, for example, that if a clutch servo is being supplied by design hydraulic pressure, but continues to exhibit slip in service, it is likely that the

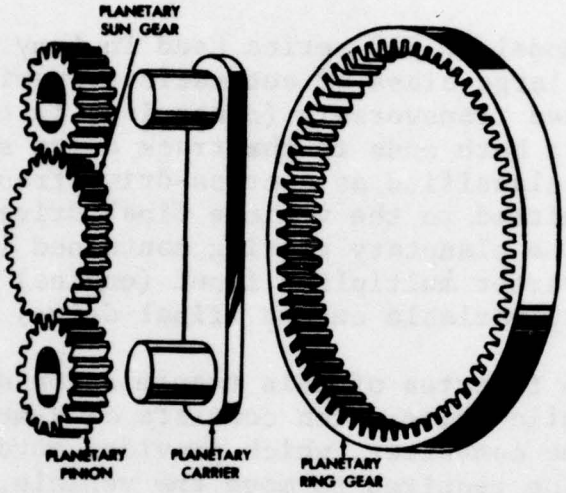

Figure 19-2. Members of a Planetary Unit

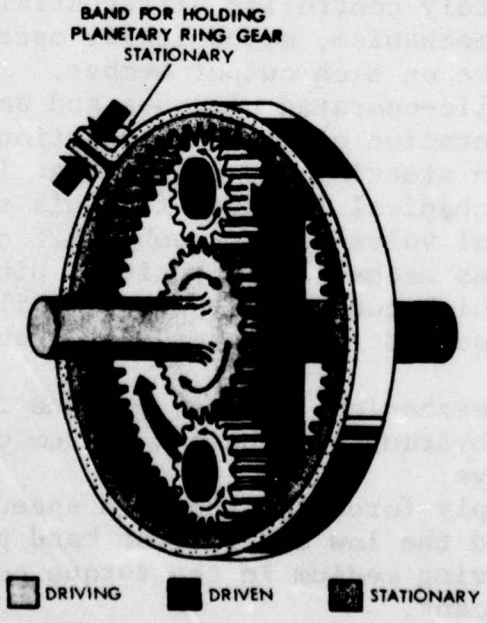

Figure 19-3. Members of a Simple Planetary Unit, showing one as Stationary Member

clutch surface is worn out. On the other hand, low servo pressure can signify a blown servo piston ring or a failure in a control valve.

19-3 DESCRIPTION OF THE TRANSMISSION

The Allison Model CD-850 series used in Army tracked vehicles is typical of the large class of automatic transmission. The transmission is placed transversely (crosswise) in the vehicle and delivers torque at both ends to the track drive sprockets. Because of this, it is classified as a cross-drive transmission. Engine power is transmitted to the vehicle final drive through the torque converter and the planetary gearing contained in the transmission. The torque converter multiplies input (engine) torque to provide an automatically variable output (final drive) torque.

The five main features of this transmission are:

(1) A hydraulic drive which consists of a multiphase, 4-element, hydraulic torque converter, which provides automatic adjustment of the output torque required to move the vehicle, depending upon driven load conditions.

(2) Four planetary gear sets: one high-low range, one reverse range and two output-planetary gear sets.

(3) A steer mechanism consisting of a steer differential controlled by two friction-disc clutches, thus eliminating the necessity for a separately controlled differential.

(4) A braking mechanism, mechanically operated, using a wet friction-disc brake on each output member.

(5) The hydraulic-operated clutches and bands which contribute to the ease of operation of the transmisstion controls.

The transmission steering and speed range is selected by the driver through mechanical linkages from his steering and shift levers to a control valve body assembly attached to the transmission. The linkages mechanically position pintles within the control valve body which control the flow of oil to proper channels to perform the required steering or speed range function.

Except for the mechanical brakes, all the functions within the transmission are hydraulic. The oil system of the transmission functions four ways:

(1) As the apply force for the high speed range and steer clutch pistons and the low and reverse band pistons (servos).

(2) As the driving medium in the torque converter.

(3) As a lubricant.

(4) As a cooling medium for the entire transmission.

250 psi, the safety valve opens and passes oil from the main oil supply line into the lubricating system line.

Other features of the transmission apart from the control valve which are pertinent to the diagnostic problem, are briefly discussed. An oil pressure and temperature sensor on the transmission are connected to respective warning lights at the driver's panel. A lubricating oil low-pressure warning light will come on if the lubricating system pressure drops to 11 ±2 psi. A torque converter high-temperature warning light comes on when the temperature of the oil returning from the main engine oil coolers reaches 280°F. (In the M60 series tank, the transmission oil is cooled by two sets of main engine oil coolers, left and right bank.) The minimum temperature of the transmission oil is controlled by two thermostats, one at each of the two flanges where the lines attach to the coolers. Each of the thermostats bypasses the oil from the "Out" line to the "In" line, until the oil temperature reaches 185°F.

The vehicle's braking system is through external hydraulic actuation of mechanical disk brakes within the transmission. The system is similar to a conventional automobile hydraulic brake system. The vehicle driver, by depressing the brake pedal charges oil pressure in a master cylinder nominally to 800 to 1000 psi which actuates two hydraulic actuators attached to each of the transmission brake apply shafts, causing mechanical rotation to engage the brake disks. If the brakes are to be permanently applied (parking, etc.), the driver actuates a cable which engages a toothed pawl to positively lock the brake apply shaft in the braked rotational position. To disengage the pawl, the driver must override the brake apply shaft position by application of more brake pedal pressure.

19-4 TROUBLESHOOTING AND MAINTENANCE

The most common failure mode of this type of transmission is through a malfunction of the main oil pump. Additional sources of malfunction are caused by improper oil level, clogged or ineffective oil coolers and filters, worn clutches or bands, improper control linkage adjustments, etc., which normally are checked and corrected by present maintenance procedures. The transmission control valve assembly has rarely failed, being rugged and simply constructed.

The transmission troubleshooting and corrective action procedures are detailed in their respective technical manuals and consist basically of observing the vehicles speed (or power output), steering, and braking performance and monitoring the driver's panel warning lights. Corrective actions on the vehicles are limited to checking the oil level, checking the proper adjustment of the

control and brake linkages, cleaning oil coolers and filters, checking and setting the proper torques on the low and reverse band adjusting screws, and adjusting the brakes. Continued malfunctions after these corrective actions, require the transmission to be replaced.

The vehicle power output malfunction is diagnosed by a series of stall tests. If the vehicle output power is less than normal, a stall test will show whether the engine or the transmission is at fault. The stall test procedure is to bring the transmission operating temperature up to between 210° to 280°F, lock the brakes, put the transmission in high range and run the engine at full throttle for 30 seconds (stop if temperature warning light comes on before this time). If the engine speed is below 1850 rpm, indications are that the engine is not operating properly. If the engine speed goes over 2400 rpm, or against the governor, there is clutch slippage in the transmission or the control linkage is improperly adjusted. This stall procedure is also used to determine band slippage or control linkage adjustment in either the low or reverse speed ranges. If the control linkage is properly adjusted and slippage occurs in any speed range, the transmission must be replaced.

As noted earlier, the control valve is a crucial unit in the functional operation of the transmission. Because of its importance, the valve body is provided with five pressure taps and one temperature tap to measure the pertinent oil pressures and temperature. The taps, as well as the entire control valve, are placed in an accessible position within the vehicle so that these measurements can be made in situ. The five oil pressure taps are for:

(1) The right steering clutch
(2) The left steering clutch
(3) The main oil pump discharge
(4) The lubricating oil
(5) The torque converter

These taps are identified with locator arrows in Figure 19-4 with corresponding numbers. The pressure readings are taken when the brakes are locked, the engine speed at approximately 1800 rpm and the oil at normal operating temperature of 210 to 280°F.

The oil level must be at the full mark. The normal acceptable range of pressures are:

Main Oil (in low, neutral or reverse)	180-210 psi
Main Oil (in high range)	106-150 psi
Right or Left Steer Clutch	Same as Main Oil in Respective Speed Range

Converter Feed	64-89 psi
Lubrication	10-40 psi

Small variations in pressures from these values do not necessarily indicate a malfunction. A malfunction will cause a radical change in pressure. Checking the oil pressures can be a valuable aid in determining the location of a malfunction in the transmission and as such will be the major diagnostic measurement.

In addition to pressure taps, four temperature probes are also shown in Figure 19-4. (Refer to locator arrow with probe symbol.) The four probes indicate:

(1) Sump oil temperature
(2) Converter output temperature
(3) Cooler discharge temperature (2 places)

Operation of the oil cooling system can be monitored adequately with these four sensors.

19-5 DIAGNOSTIC MEASUREMENTS

The proper operation of the transmission depends upon the correct adjustment of the control linkages which position the control valve pintles, the correct level of oil in the transmission, clean oil coolers and filters and properly adjusted bands and brakes. The diagnostician must decide on the basis of available time if all or part of these adjustments are to be made prior to the diagnostic test or whether they may be made as a result of diagnostic test readout instructions.

Note that the operating conditions for the pressure tests are identical to the stall test except for the rpm settings (loading by the engine). A diagnostic pressure test with acceptable readings could proceed to a stall test in the respective speed ranges by an automatic throttle increase to full rack to check out clutch or band slippage or improper control linkage adjustment. With prior adjusted linkages, this diagnostic test procedure would immediately isolate a major malfunction to that of slippage.

The oil pressure diagnostic measurements will first compare the main oil and converter oil pressures. If the main oil pressure or the converter oil pressure is too low, check the oil level. If the oil is up to the full mark, check the main-oil filter to see if it is clean. The filter is located behind the control valve body assembly on top of the transmission. If the filter is clean, check the converter oil pressure regulator valve for proper function. If the condition still exists, indications are there is an internal leak in the oil system or malfunctioning oil pump. If

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the lubrication oil pressure is too low (below 8 psi at 1800 engine rpm), indications are:

(1) The lubrication regulator valve is stuck in an open position

(2) The oil filter screen is clogged

(3) The converter regulator valve is stuck in a closed position

(4) There is an oil leak in the main, converter, or lubrication oil circuit.

If the checks listed above do not correct the trouble, the transmission must be disassembled for an inspection of the input oil pump and oil circuits.

The transmission oil temperature can be measured for the purpose of checking the proper functioning of the oil cooler thermostatic valves. Also, a high oil temperature will light up the warning light, thereby testing the light's condition.

The diagnostic testing of a mechanical brake system will require a sensor (or operator observation) which will indicate vehicle movement as a result of malfunctioning brakes. Continued malfunction after proper control linkage and brake adjustment will require a replacement of the transmission.

19-6 CANDIDATE TEST POINTS

A listing of candidate test point parameters is included in Table 19-1 from which the designer may select those of most value to his particular design. The listing includes three helicopter drive trains, three automotive types and six amphibious types.

TABLE 19-1. CANDIDATE TEST POINTS

Light Helicopter (UH-1H) (Single Engine and Rotor) Transmission and Drive Trains
(1) Main transmission oil temperature tap
(2) Angle gearbox oil temperature tap
(3) 90° tail rotor gear box oil temperature tap
(4) Main transmission oil level tap
(5) Angle gearbox oil level tap
(6) 90° tail rotor gearbox oil level tap
(7) Main transmission chip detector electric tap
(8) Angle gearbox chip detector electric tap
(9) 90° tail rotor chip detector electric tap
(10) Accessory gearbox chip detector electric tap

TABLE 19-1. CANDIDATE TEST POINTS (Continued)

(11) Main transmission oil filter Δp
(12) Main transmission input quill temperature tap
(13) Forward shaft hanger bearing temperature tap
(14) Intermediate shaft hanger bearing temperature tap
(15) Aft shaft hanger bearing temperature tap
(16) Swash plate bearing temperature tap
(17) Transmission top vibration pickup point
(18) Transmission bottom vibration pickup point
(19) Tail assembly vibration pickup point
(20) Mast low frequency vibration pickup point
Medium Helicopter (CH47) (Twin Engines and Rotors) Transmission and Drive Trains
(1) Combining transmission oil temperature tap
(2) Aft rotor transmission oil temperature tap
(3) Forward rotor transmission oil temperature tap
(4) Combining transmission oil level tap
(5) Aft rotor transmission oil level
(6) Forward rotor transmission oil level
(7) Combining transmission chip detector electrical tap
(8) Aft rotor transmission chip detector electrical tap
(9) Forward rotor transmission chip detector electrical tap
(10) Combining transmission port side vibration pickup point
(11) Combining transmission starboard side vibration pickup point
(12) Aft and forward transmission top vibration pickup point
(13) Aft and forward transmission bottom vibration pickup point
(14) Aft and forward masts, low frequency vibration pickup point
(15) Aft and forward swash plates, bearing temperature tap
(16) Rear rotor forward drive shaft hanger bearing temperature tap
(17) Forward rotor forward drive shaft hanger bearing temperature tap
(18) Rear rotor rear drive shaft hanger bearing temperature tap
(19) Forward rotor rear drive shaft hanger bearing temperature tap
(20) Aft and forward rotor drive shaft intermediate hanger bearing temperature tap
(21) Transmission oil cooler entry and exit temperature taps

TABLE 19-1. CANDIDATE TEST POINTS (Continued)

Heavy Helicopter (HLH) (Triple Engines and Twin Rotors) Transmission and Drive Trains
(1) Combining transmission oil temperature taps at port, center and starboard input shaft bearing housings
(2) Combining transmission return oil temperature tap
(3) Aft and forward transmission return oil temperature tap
(4) Combining transmission oil level tap
(5) Aft and forward transmission oil level tap
(6) Combining, aft and forward transmission chip detectors electrical tap
(7) Combining transmission port, center and starboard vibration pickup point
(8) Aft and forward transmission top vibration pickup point
(9) Aft and forward transmission bottom vibration pickup point
(10) Aft and forward transmission input bearing vibration pickup point
(11) Combining transmission oil cooler entry and exit temperature taps
(12) Aft and forward transmission oil cooler entry and exit temperature taps
(13) Port, center and starboard engine drive shaft hanger bearing temperature tap
(14) Slant drive shaft hanger bearing temperature tap
(15) Synchronous shaft hanger bearing temperature tap
(16) Aft and forward masts low frequency vibration pickup point
(17) Aft and forward swash plate bearing temperature tap
(18) Transmission oil cooler entry and exit temperature taps
Automotive Transmission (M60A152 Tank CD850-S) Automatic Cross Drive
(1) Transmission input shaft speed (engine speed)
(2) Transmission oil level tap
(3) Transmission oil temperature tap at oil cooler entry/exit
(4) Transmission oil cooler fan speed pickup
(5) Cooler fan thermostatic control current tap
(6) Transmission main oil pressure tap
(7) Transmission lube oil pressure tap
(8) Converter in and out oil pressure taps
(9) Converter out oil temperature tap
(10) Low and high range pressure taps
(11) Left and right steering clutch oil pressure taps
(12) Left and right servo piston pressure taps

TABLE 19-1. CANDIDATE TEST POINTS (Continued)

(13) Transmission oil filter differential pressure taps (14) Steering and high-low brake adjustment position indicator (15) Transmission vibration pickup point (16) Chip detection electrical pickup
Automotive transmission (M113 Carrier TX-100-1) Automatic In-line Drive
(1) Transmission input shaft speed (engine speed) (2) Transmission output shaft speed (3) Transmission oil level tap (4) Transmission oil temperature tap at oil cooler entry and exit (5) Transmission main oil pressure tap (6) Transmission lubrication oil pressure tap (7) Converter in and out oil pressure taps (8) Converter out oil temperature tap (9) Front governor oil pressure tap (10) Rear governor oil pressure tap (11) Transmission lockup pressure tap (12) Chip detection electrical pickup
Automotive Transmission (M3SA2 and M1S1A2) Manual Synchromesh
(1) Transmission oil level tap (2) Transmission oil temperature tap (3) Chip detector electrical pickup (4) Transmission vibration pickup point
Amphibious Transmission (LARC V, LARC XV and LARC IX) Converter and F-N-R Transmission
(1) Torque converter input speed (2) F-N-R Transmission output speed (3) Converter and transmission oil level tap (4) Converter entry and exit oil pressure taps (5) Converter exit oil temperature tap (6) Transmission oil pressure tap (7) Transmission lube oil pressure tap (8) Transmission lockup pressure tap (9) Oil cooler Δ_T taps (10) Oil filter Δ_p taps

TABLE 19-1. CANDIDATE TEST POINTS (Continued)

Amphibious Transmission (LARC XV) H-M-L Transfer and Differential Transmission
(1) Main oil pressure tap (2) Shifter clutch oil pressure tap (3) Oil filter Δ_P taps (4) Oil cooler Δ_T taps (5) Transmission oil level tap
Amphibious Transmission (LARC V) Differential Transmission
(1) Oil level indicator tap (2) Oil temperature indicator tap
Amphibious Transmission (LARC V, LARC XV and LARC IX) Right Angle Drive Assembly
(1) Oil level indicator tap (2) Oil temperature indicator tap
Amphibious Transmission (LARC LX) Combining Transmission
(1) Oil level indicator tap (2) Oil pressure tap, cooler entry (3) Oil cooler entry and exit temperature taps
Amphibious Transmission (LARC LX) Marine Transmission
(1) Oil level indicator tap (2) Oil pressure tap, cooler entry (3) Oil cooler entry and exit temperature taps (4) Oil filter Δ_P taps (5) Air pressure tap, control valve(s)

PART VI SURVEY OF TEST SYSTEMS FOR APPLICATION TO MECHANICAL, HYDRAULIC AND PNEUMATIC MATERIEL

CHAPTER 20
SURVEY OF EXISTING MANUAL TEST SYSTEMS

20-1 GENERAL

The purpose of Part VI (Chapters 20 and 21) is to provide the reader with "broad brush" survey material describing manual and automatic test systems which may typically be interfaced with old and newly designed mechanical, hydraulic, and pneumatic materiel. Both Army (Ref.1) and commercial test equipment are described. The survey is rather limited and has the intent of presenting manufacturers who are in the business with examples of their testing products. The test systems described should not be construed to be a complete listing of all manufacturers off-the-shelf test systems. The systems presented are those known to be of above average utility.

20-2 MANUAL TEST SYSTEMS

Manual test systems are defined as test equipment, instruments and test stands which measure at least two or more parameters in a given system. This rule has been followed throughout Chapter 20 with the exception of a few unique instruments which the authors felt should be mentioned (oil analysis instruments, etc.). Readers interested in small, portable single parameter measuring instruments are referred to Reference 2, "Investigation of Inspection Aids". That technical report is a survey of instruments useful for aircraft and ground vehicle inspections. Instruments are included which treat the problems of depth measurement, cracks, wear, slippage measurement, alignment, flexing, leakage, and delamination-debonding, and corrosion.

The manual test systems in this guide are presented in a fixed format providing manufacturer information, top level system specification data, a photograph of the system, and a brief description of its purpose and capability. The manual test system survey is organized into the following sections or types of systems.

- Test Stands
- Mobile Test Machines
- Oil Analysis Equipment
- Portable Hydraulic System Testers
- Leak Testers and Monitors
- Dynamometers
- Torque and Speed Testers
- Engine Analyzers
- Ignition Analyzers
- Infrared Analyzers
- Vibration Systems
  - Vibration Measurement Systems
  - Bearing Analysis Systems
  - Vibration Monitoring and Balancing Systems
  - Real Time Vibration Analyzers
- Miscellaneous Measuring Systems

20-2.1 TEST STANDS

Numerous hydraulic, pneumatic, and mechanical test stands are used by DoD A small sampling of test stands follows. Some are in the U. S Army inventory; others are commercial products available by order.

Name:	Aircraft Hydraulic Test Stand
Manufacturer:	Greer Hydraulics, Inc., 5930 West Jefferson Blvd., Los Angeles, Ca. 900016/ (213) 870-9161
Model:	HA109-1 Figure No.: 20-1
Size:	7ft. W x 6ftH x 4ftD Weight:
Power Requirements:	220/440 VAC -60 hertz - 3 phase
National Stock Number:	4920-00-490-3286

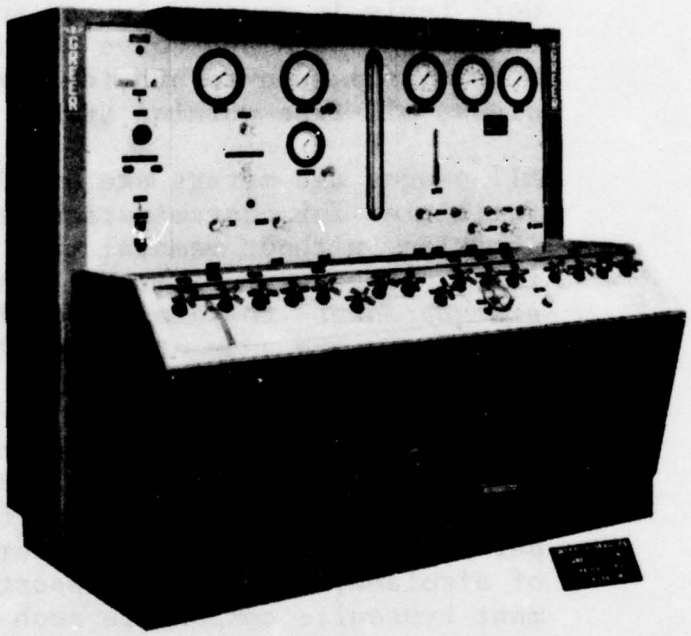


Figure 20-1. Greer Universal Hydraulic Component Test Stand.

Description: Functional arrangements on the HA 109-1 Test Stand are such that testing of components is easy, fast and efficient. All controls are mounted on an inclined panel at the front of the machine within easy reach of the operator. Pressure connecting ports are mounted on an inclined panel on the front of the sump and face away from the operator so that pressure connections to the equipment under test are within easy reach. These

ports are positioned adjacent to the control valves for ease of identification. Return ports are mounted on the vertical panel of the sump facing the operator and opposite the pressure ports. With this arrangement the operator is protected against discharge of hot oil if a valve is inadvertently left open. This arrangement also makes it unnecessary to reach across and around the equipment under test in order to operate the valves. A perforated stainless steel work table is mounted in the sump below the valve ports and above the inclined bottom of a sump to provide a flat, clean, oil-free working area.

All gauges and meters are provided with a facilities for contamination-free re-calibration, without removal from the machine. All gauges utilize 6" dials and are guaranteed to 1% accuracy full-scale. Flowmeters are guaranteed to 2% accuracy full-scale.

HA-109-1 Test Stand is rated for 5,000 PSI maximum, 3,000 PSI normal operating pressures and flows from 5 to 60 gallons per minute. It is designed for the test of airplane, missile or support equipment hydraulic components such as actuators, control valves, regulators, accumulators, specialty valves, manifold subsystems and systems.

Name:	Hydraulic Maintenance Center
Manufacturer:	Schroeder Brothers Corporation, Nichol Avenue, Box 72, McKees Rocks, Pa. 15136/(413) 771-4810
Model:	HMC-250 Figure No.: 20-2
Size:	129 in. L x 56 in H x 48 in D Weight: 5750 lbs.
Power Requirements:	230/460 VAC, 3 Phase, 60 Hertz
National Stock No.:	- -

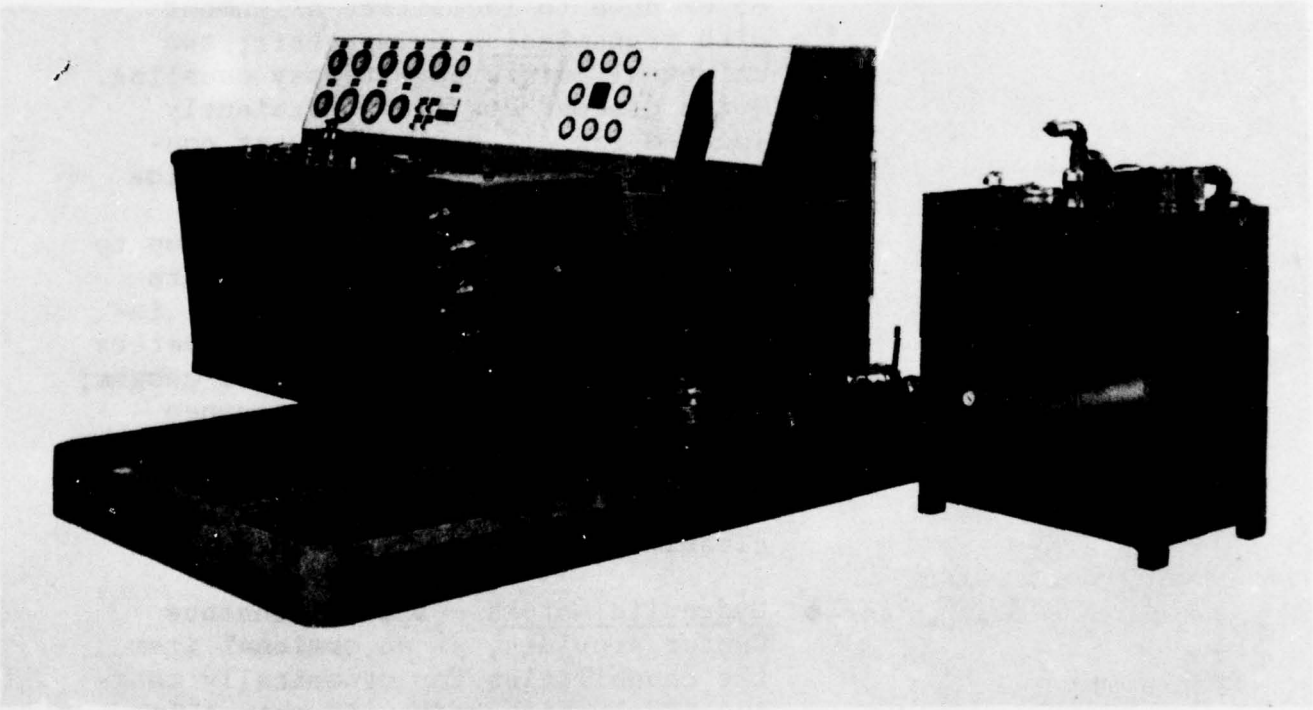


Figure 20-2. Schroeder Hydraulic Maintenance Center.

Description: The Schroeder Model HMC-250 test stand provides testing capabilities for hydraulic power shift transmissions, motors, pumps, valves and cylinders under simulated operating conditions. It utilizes quick select levers to permit rapid test circuit selection and contains full-flow filtration to maintain a high cleanliness level in the testing fluid. The instrumentation includes 8 pressure guages (five 600 PSI, two 200 PSI);

2 flow meters, 1 tachometer. Additional gauges for component testing include 6 pressure gauges (four 5000 PSI, one 600 PSI and one 300 PSI); 1 - 220°F. temperature gauge.

The following capability is provided:

- Power Shift Transmissions - The Maintenance Center includes a transmission stand and drain sump. The expandable drive line is hydraulically operated up or down to facilitate alignment with transmission drive shaft; two universal joints permit easy coupling. Quick disconnects are conveniently located for all gauge and test connections. Test capabilities provide 340 ft./lbs. of torque to rotate transmission in either direction up to 2500 RPM. Shift speed and pressure setting can be determined. Panel instrumentation includes two flow meters to check for hydraulic pressure gauges; and a tachometer. The Maintenance Center has a built-in sump pump which pumps fluid from the sump through 10-micro filters to maintain efficient cleanliness level in the fluid.

- Hydraulic Motors - The Maintenance Center provides, as an optional item, the capabilities for dynamically testing and loading hydraulic motors in either direction. Actual "on the machine" conditions are simulated to determine motor efficiency and detect possible external leakage. Simplified controls are handy to load and control test pressures; convenient tachometer, pressure gauges and flow meters show performance characteristics in the testing procedure.

- Hydraulic Valves and Cylinders - Flow up to 38 GPM and pressures to 5000 PSI are available for testing valves and

and cylinders. Double-acting cylinders can be cycled and tested without extra accessories through using the "Quick Select" lever on the Maintenance Center. Valves requiring two different pressures up to 5000 PSI can also be tested. Quick disconnects simplify hook-up connections.

Name:	Hydraulic Test Stand
Manufacturer:	McDonnell Douglas Astronautics Company, 5301 Bolsa Ave., Huntington Beach, Ca. 92647 /(714) 896-3311
Model:	Part No. 8523711 Figure No.: 20-3
Size:	50 in. L x 45 in. H x 30 in. D Weight: 1000 lbs
Power Requirements:	220/440 VAC, 60 Hertz, 3 Phase
National Stock No.:	4935-00-677-8187

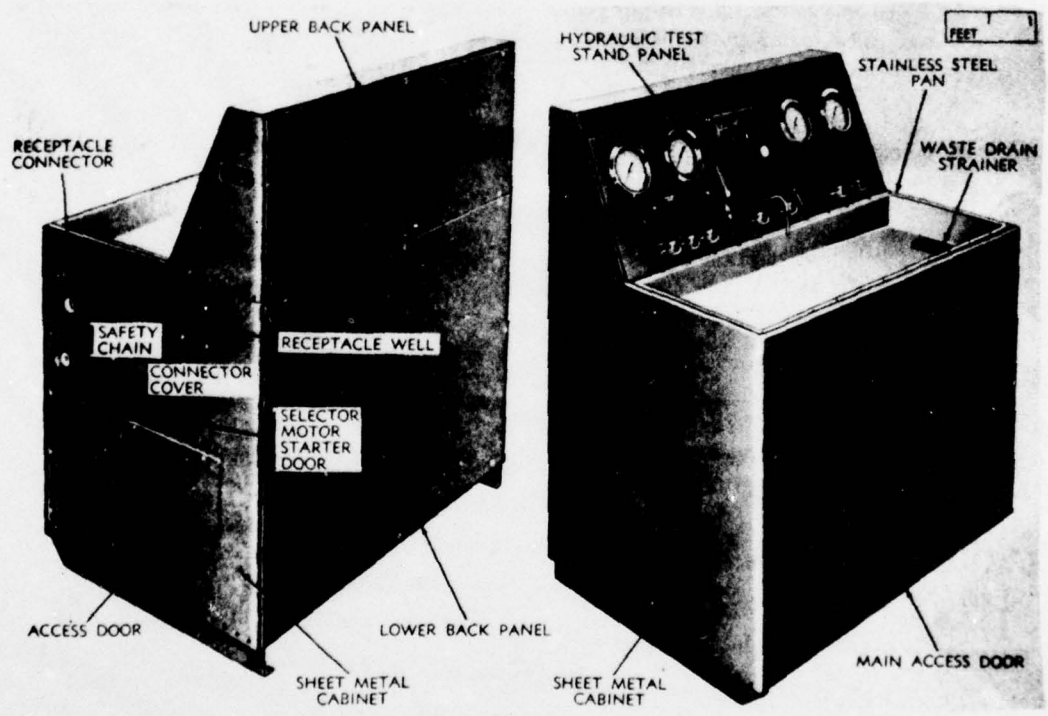


Figure 20-3. McDonnell Douglas Hydraulic Test Stand.

Description: The hydraulic test stand supplies hydraulic fluid to components under test at regulated pressure ranging from 2 to a maximum of 5,500 psi. The stand incorporates three systems: motor pump, hand pump, and return, each system functioning independently of the other.

Except when extremely high or low pressures are required for static tests, the motor pump system supplies hydraulic fluid for the flow and static tests of the components. A hand pump system is available when extremely high or low pressures are required. A reservoir tank and pump fluid-filter components are common to the two pump systems. The test stand supplies a maximum pressure of 5,500 psi for the hand pump and 3,600 $\pm$ 100 psi for the motor pump system.

The return system may be used with either the motor pump or the hand pump system. During component testing, the return system diverts fluid to a graduated tube on the hydraulic test stand panel, so that the operator may measure internal leakage of a component under test. The test stand also supplies pressure to the hydraulic flow test cabinet, which is used in conjunction with the single-channel valve tester to test solenoid-operated, 4-way valves.

Name: Hydraulic Pump and Accessories Test Stand
Manufacturer: Testek, Inc., 12271 Globe Road, Livonia, Michigan 48150/(313)422-7607
Model: 17221
Size:
Power Requirements:
National Stock No.:
Figure No.: 20-4
Weight:

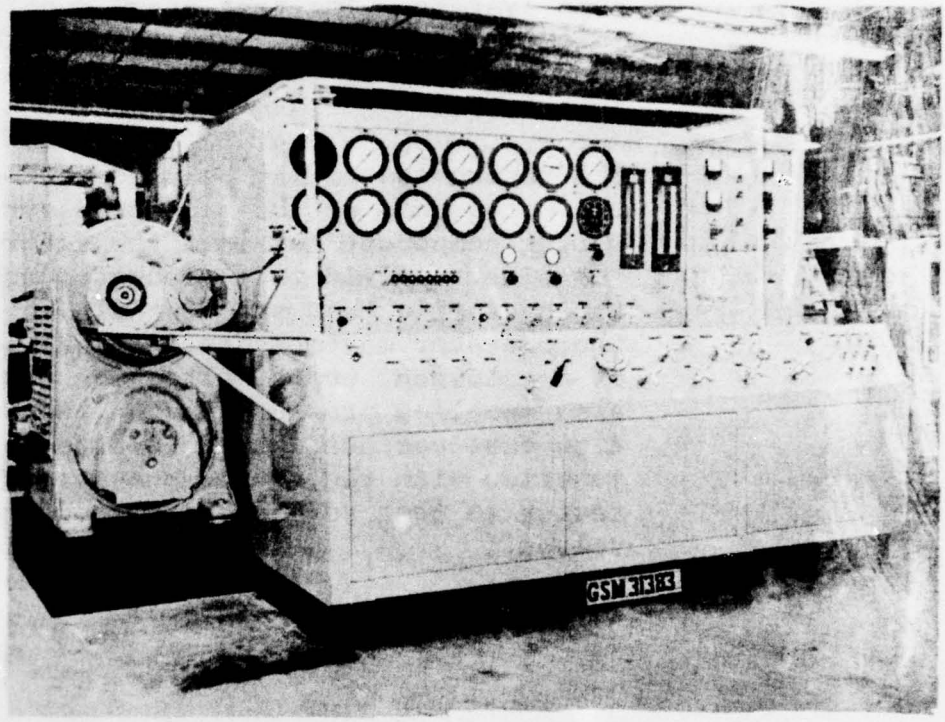


Figure 20-4. Testek's Hydraulic Pump and Accessories Test Stand

Description: The Model 17221 test stand is designed to demonstrate the proper functioning of various aircraft hydraulic pumps and hydraulic accessories for all current models of transport aircraft. It is self-contained, requiring only normal shop services for its operation. The test stand includes a test console with all the necessary gauges, valves, ports and hoses for testing pumps and accessories; a sliding plexiglass shield for the operator's safety; and a pump drive system of sufficient power to drive the pumps on test.

For testing pumps a variable speed drive is provided, adequate in power and speed range for the pump manufacturer's requirements. A boost pump draws fluid from the reservoir through a filter to the inlet port of the test pump. Test pump output returns to reservoir through a flowmeter and cooler. Throttling valves in port circuits control inlet and loading pressures. An automatic temperature controller maintains the desired fluid temperature. Drain port leakage circuit permits measurement of leakage flow from pump drain port through a low range flowmeter.

For testing hydraulic accessories such as valves, actuating cylinders, pressure regulators, accumulators, etc., a high pressure system is provided rated to the requirements of the accessories to be tested. The pump output is delivered through a filter to the high pressure manifold with outlets for the types of accessories on test. The return flow is temperature controlled before entering the reservoir. A four way selector valve is provided for cylinder testing.

Name: Hydraulic Pump and Accessories Test Stand
Manufacturer: Avitech, Inc., 2 Highland Street, Port Chester, New York 10573/(914)939-4050
Model: 171 Figure No.: 20-5
Size: Weight:
Power Requirements: 230 VAC, 60 Hz, 3 Phase; shop air and cooling water
National Stock No.:

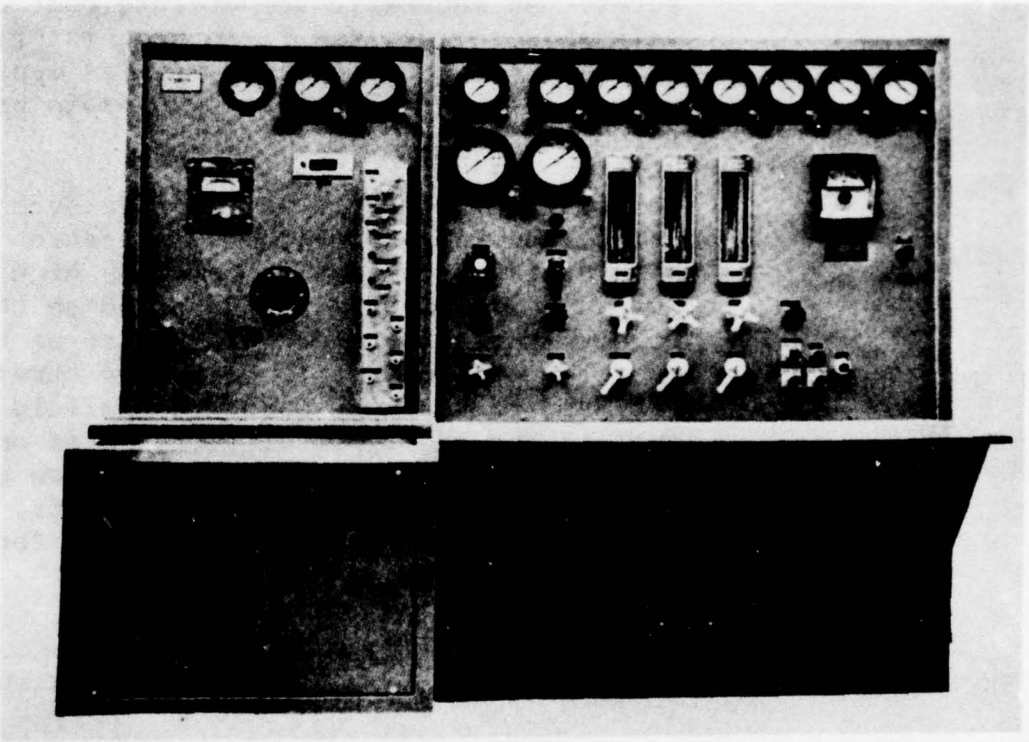


Figure 20-5. Avitech's Hydraulic Accessory Test Stand

Description: Avitech's Hydraulic Accessory Test Stand is designed for one man operation to test pump, valves, pressure switches, accumulators, pistons, linear and rotary actuators, and solenoid valves. Its design includes 60 HP drive, 0-6500 rpm, oil supply system rated at 5000 psig, safety interlocks, multiple gauges for a variety of pressure measurement and multiple glass tube flowmeters for wide range capability and accuracy. Optional capability includes hydraulic motor testing and special HP drive and speed specification.

Name:	Universal Hydraulic Test Stand
Manufacturers:	Teledyne Sprague Engineering, 19300 South Vermont Ave., Cardena, Ca. 90248/(213)327-1610
Model:	S-169 Figure No.: 20-6
Size:	132 in W x 78 in H x 39 in D Weight:
Power Requirements:	230 VAC, 60 Hz
National Stock No.:	

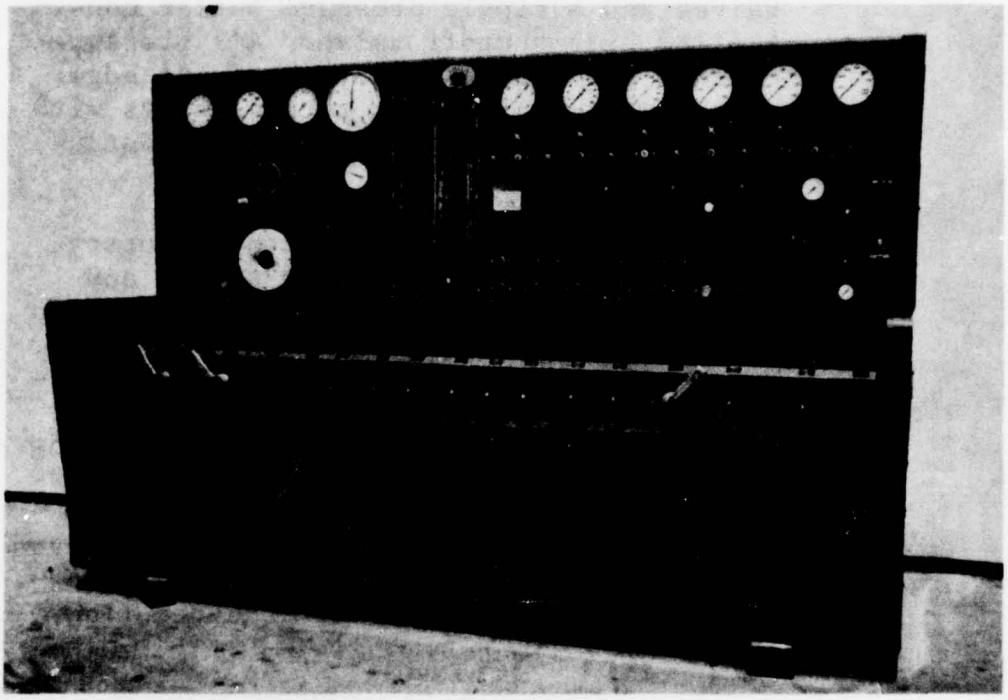


Figure 20-6. Teledyne Sprague's Universal Hydraulic Test Stand

Description: The Model S-169 Universal Hydraulic Test Stand provides facilities for testing all hydraulic system components. Its capacity is 20 gpm. at 3000 psi. Maximum pressures are available to 500 psi and static pressures to 20,000 psi. It is ideal for the shop or lab which must test many different types of equipment.

Test fluid storage facilities are provided by a 110 gallon reservoir. Micronic fluid

filtration is provided by a low pressure filter on the boost system. An air bleed valve or plug is provided in the top cover of the low pressure filter to admit purging air from the test stand system. A filter drain is also provided to permit draining the filter for maintenance purposes.

The flow system is comprised of: a four-way valve with inlet and outlet shutoff valves and a single pressure outlet controlled by a shutoff valve. All pressure outlets are located along the front edge of the work tray. Four return inlets with shutoff valves are located on the instrument panel.

Three flowmeters of one percent accuracy are incorporated in the flow system and provide sufficient range for flow tests up to the delivery capacity of the main pump. Return flow through the flowmeters is controlled by shutoff valves and a flowmeter bypass valve is provided to permit routing return flow directly to reservoir by passing the flowmeter when not required for test purposes. Three flowmeter outlets are also provided to permit direct connection from test component to the required flowmeter.

Hydraulic pumps can be tested to manufacturer's specifications. The pump test system is comprised of a variable speed pump drive pad with a capacity of approximately 20 h.p. at 4000 rpm in either direction of rotation plus all necessary controls.

Name: Hydraulic Flow/Pressure Test Stand
Manufacturer: Kahn and Co., Inc., 885 Wells Road, Wethersfield, Conn. 06109/(203)529-8643
Model: 181-400 Series Figure No.: 20-7
Size: 48 in W x 60 in H x 20 in D Weight: 1500 lbs.
Power Requirements: 230 VAC 60 Hz, 3 Phase
National Stock No.:

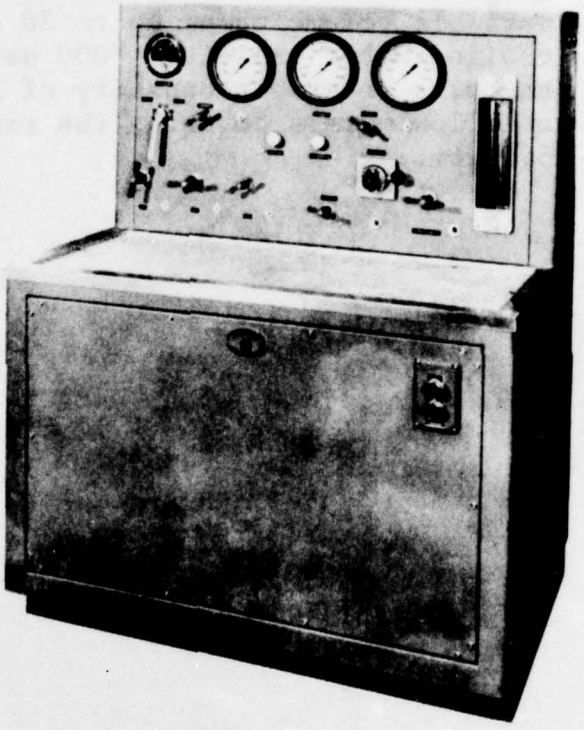


Figure 20-7. Kahn's Hydraulic Flow/Pressure Test Stand

Description: The Kahn 181-400 series test stand was designed to meet the wide variety of design, production and quality control testing applications common to fluid systems or fluid component manufacturers. A wide variety of standard test stand configurations are offered to serve the needs for pressure, flow, durability testing or calibration of a wide variety of components such as check valves, relief valves,

solenoid valves, regulating valves, needle valves, selector valves, manifolds, pressure transducers, pressure switches, fittings, and fluid restrictors.

The 181-400 series test stand features 1500 and 3000 psi designs, stainless steel sink reservoir and drain tray, compatible with wide range of fluids, high accuracy gauges and meters, water saver valve, and gauge snubbers. Various models come with variable volume pump, up to 20 gpm of cooling water capacity, 5000 psi pressure gages, a reservoir capacity of 20 gallons, and flow meters covering the range of .5 - 5.0 gpm.

Name:	Fuel Control Test Stand
Manufacturer:	Kahn and Company, Inc., 885 Wells Road, Wethersfield, Conn. 06109/(203)529-8643
Model:	181-069 Figure No.: 20-8
Size:	13 ft L x 9 ft. H x ft.D Weight: 5000 lbs.
Power Requirements:	440 VAC, 60 Hertz, 3 Phase
National Stock No.:	4920-00-839-7016

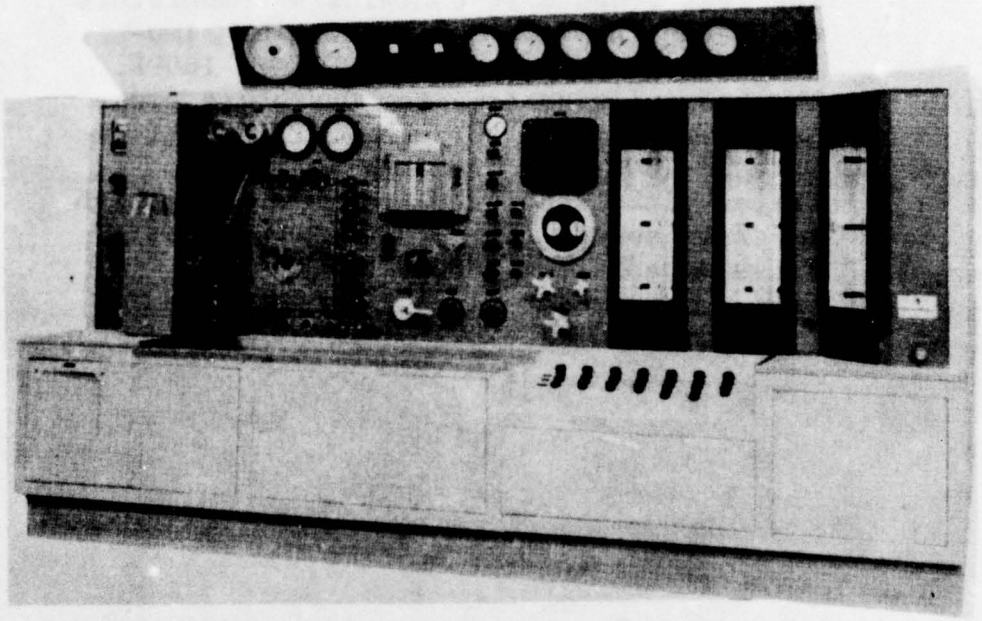


Figure 20-8. Kahn Fuel Control Test Stand.

Description: The test stand provides all necessary systems; pneumatic, hydraulic, electrical and variable speed drives, and required instrumentation to perform functional checkouts and initial calibration of fuel controls. It was designed for calibrating and overhaul testing of the Hamilton Standard JFC-31-9 and Chandler Evens TA-1 and TA-2 fuel controls as used on the Lycoming Division, AVCO Corporation T-53 and T-55 jet engines. Options are also available to increase testing capability to include fuel controls for the T-63 JFTD-12, T-64,

PT6A and T-74.

A facility skid and air dryer is furnished as a part of the test stand which contains the M-G sets, refrigeration unit and electrical control panel. A sink is provided in the work area with electrical controls and overhead instrument panel lights on the front of the stand. The facility skid is open, all components mounted on channel iron supports.

The test stand also contains a temperature simulator unit for calibration at simulated temperatures from 67°F to + 160°F. The hydraulic system provides boost pressures from 0 PSIG through 75 PSIG at flow rates 0-7000 pph. Two variable speed drives with associated controls accomplish N_1 drive speeds from 5-5000 RPM and N_2 drive speeds from 0-8000 RPM.

Name:	Transmission Test Stand
Manufacturer:	Bell Helicopter Company, P.O. Box 482, Fort Worth, Texas 76101/(817)280-2011
Model:	204-040-009-15GIS-2(UH-1) Figure No.: 20-9
Size:	303 in. L x 144 in. H x 90 in D Weight:
Power Requirements:	440 VAC, 60 Hertz, 3 Phase

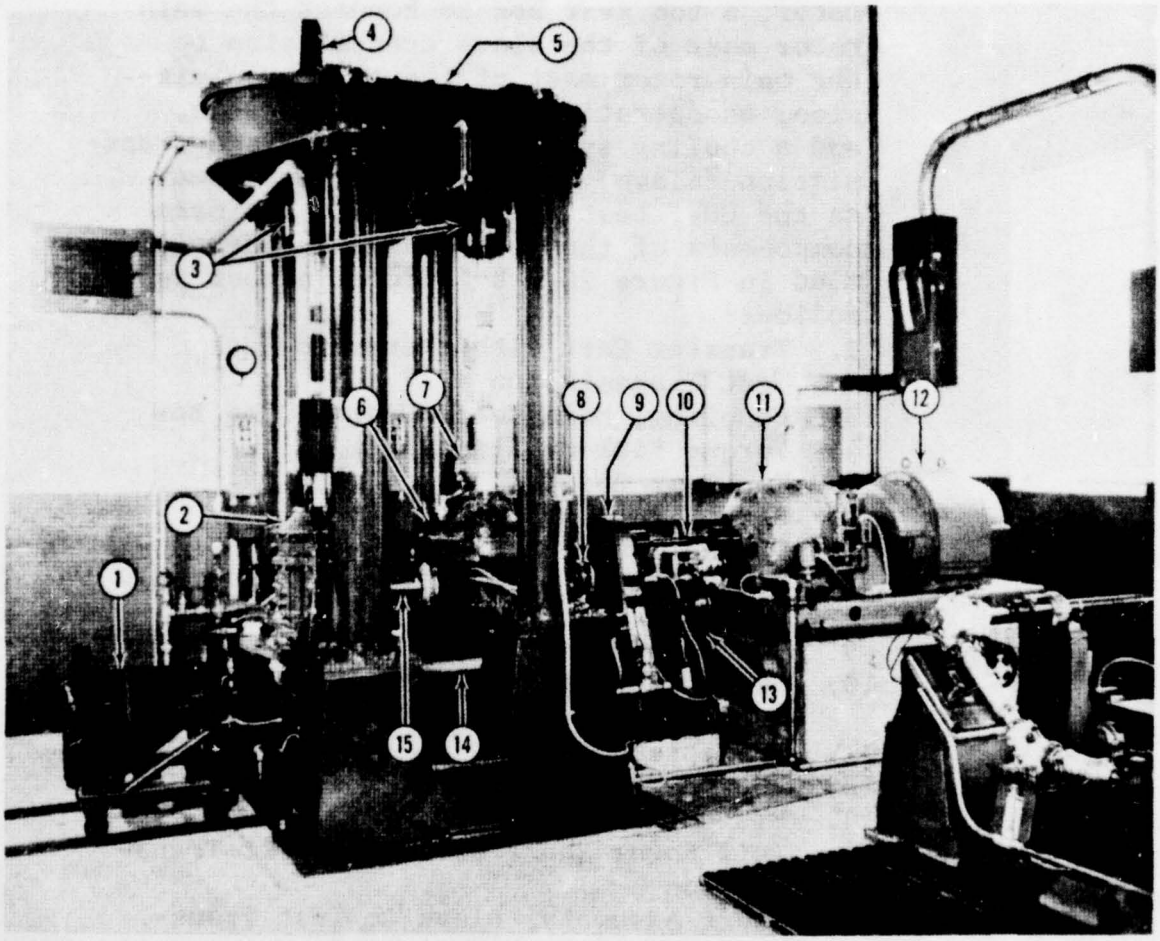


Figure 20-9. Bell Helicopter UH-1 Transmission Test Stand.

Description: The UH-1 Transmission Test Stand has been designed to test functionally the UH-1 helicopter transmission, 42 degree gear box and the 90 degree gear box. A transmission test run is used, with induced loads and speeds to simulate forces of

actual flight. Verification of correct assembly, adequate lubrication, backlash and gear patterns of major components is determined by inspection of the transmission after the test run.

The Test Run Stand incorporates a 200 HP AC motor and a magnetic coupler, a speed-up box, a slave transmission, a torqueing motor, a top gear box to connect the main rotor mast of the slave transmission to the main rotor mast of the test transmission, an operating and control console, and a cooling system. The test stand transmission (slave) is essentially the same as the UH-1 test transmission. The main components of the test stand are identified in Figure 20-9 by circled number as follows:

1. Transfer Cart with Hydraulic Jack
2. Test Transmission
3. Coupling, Main Rotor Mast to Top Box
4. Torque Pick-up Slip Ring
5. Top Gear Box
6. Slave Transmission
7. Torque Motor
8. Input Shaft, Speed Box to Slave Transmission
9. Speed Increaser Box
10. Shaft Assembly, Magnetic Coupling to Speed Increaser Box
11. Magnetic Coupling
12. 200 HP Motor
13. Fluid Coupling
14. Tail Rotor Shaft Assembly, Test Transmission
15. Shaft Assembly, Slave to Test Transmission

Name: Pneumatic Accessories Test Machine
Manufacturer: Greer Hydraulics, Inc., 5930 West Jefferson Blvd., Los Angeles, Ca. 90016/(213) 870-9161
Model: JEPA-1 Figure No.: 20-10
Size: Weight:
Power Requirements:
National Stock No.:

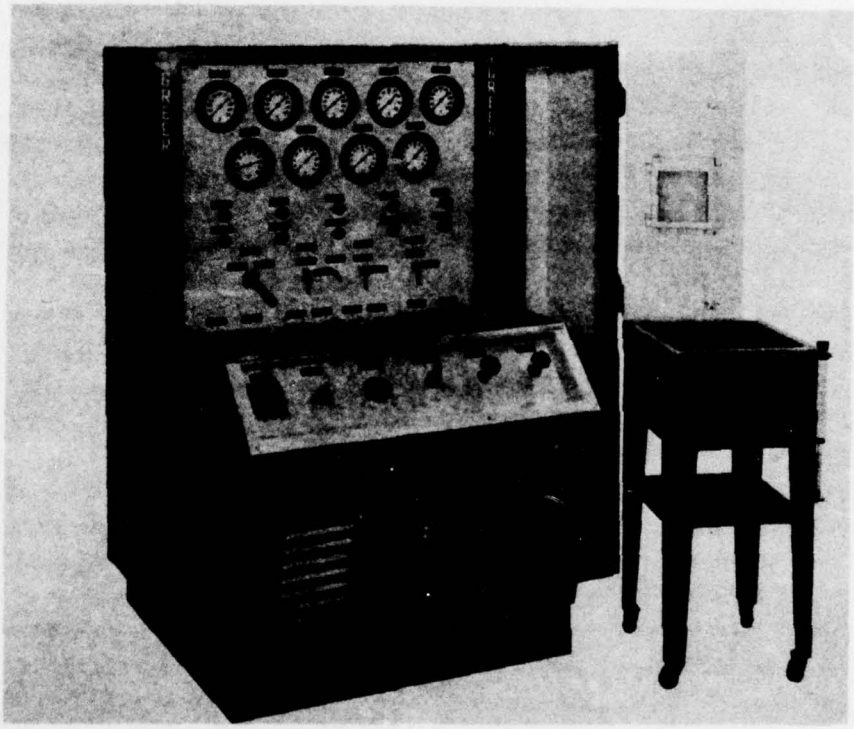


Figure 20-10. Greer Hydraulic's Pneumatic Test Machine

Description: The Pneumatic Accessories Test Machine, model JEPA, is used to test the performance and operation of pneumatic system components. The unit provides unregulated high-pressure, filtered air for static tests and regulated, high-pressure air for testing pneumatic components. The JEPA provides low pressure air by filtering an external air supply. In addition to the main console which houses the electrically driven compressor, the various valves and

piping networks, this machine includes a burst chamber and a separate leak test tank for conducting internal leakage tests of components.

20-2.2 MOBILE TEST MACHINES

Several kinds of mobile test machines are used in the Army and others are available commercially. They include mobile hydraulic test stands, turbine engines monitoring and test stands and aircraft servicing equipment. A small sample of these machines follows:

Name:	Mobile Hydraulic Test Stand
Manufacturer:	Janke and Co., Inc., Harrison Street, P. O. Box 448, Dover, New Jersey 07801/ (201) 361-8550
Model:	D5B Figure No.: 20-11
Size:	80 in L x 53 in H x 56 in D Weight: 250 lbs.
Power Requirements:	None (self-driven by gasoline engine)
National Stock No.:	4920-00-141-8801

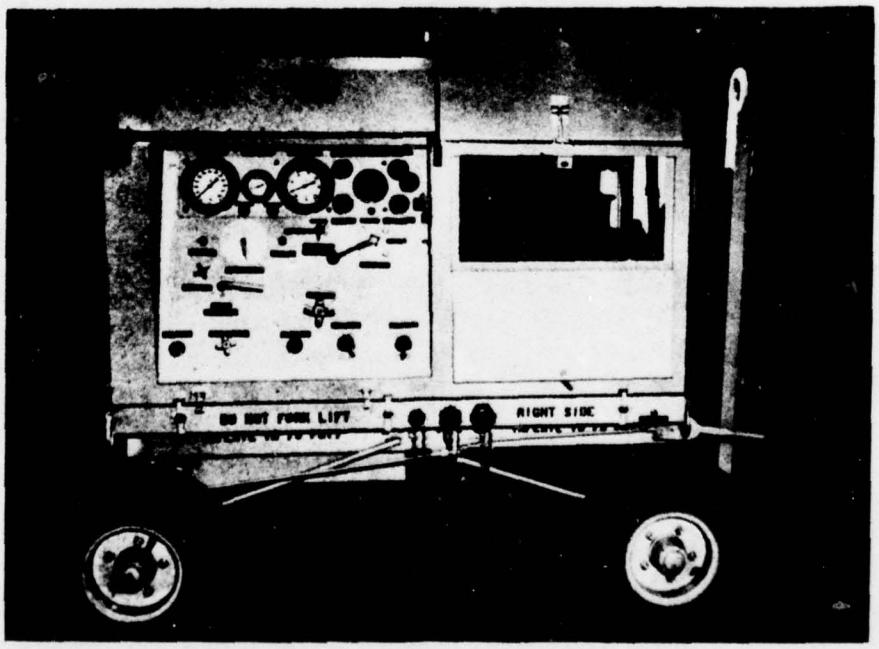


Figure 20-11. Janke D5B Mobile Hydraulic Test Stand.

Description: The D5B Mobile Test Stand is a self-contained, mobile hydraulic testing unit used to test aircraft hydraulic systems. It's

gasoline engine develops 31 HP psi gauge pressure. The D5B is typically used to perform pressure and integrity test of aircraft hydraulic systems, lines, pumps, etc.

Its capability includes the supply of hydraulic fluid from 0 to 10 GPM at operating pressures from 800 to 5000 psi. The control panel indicates hydraulic pressure, suction pressure and flow.

Name:	Portable Hydraulic Test Machine
Manufacturer:	Greer Hydraulics, Inc., 5930 West Jefferson Blvd., Los Angeles, Ca. 90016/(213)870-9161
Model:	HPE-8S Figure No.: 20-12
Size:	96 in L x 56 in H x 72 in W Weight: 4900 lbs.
Power Requirements:	440 VAC, 60 Hertz, 3 Phase (Gasoline engine models are available)
National Stock No.:	

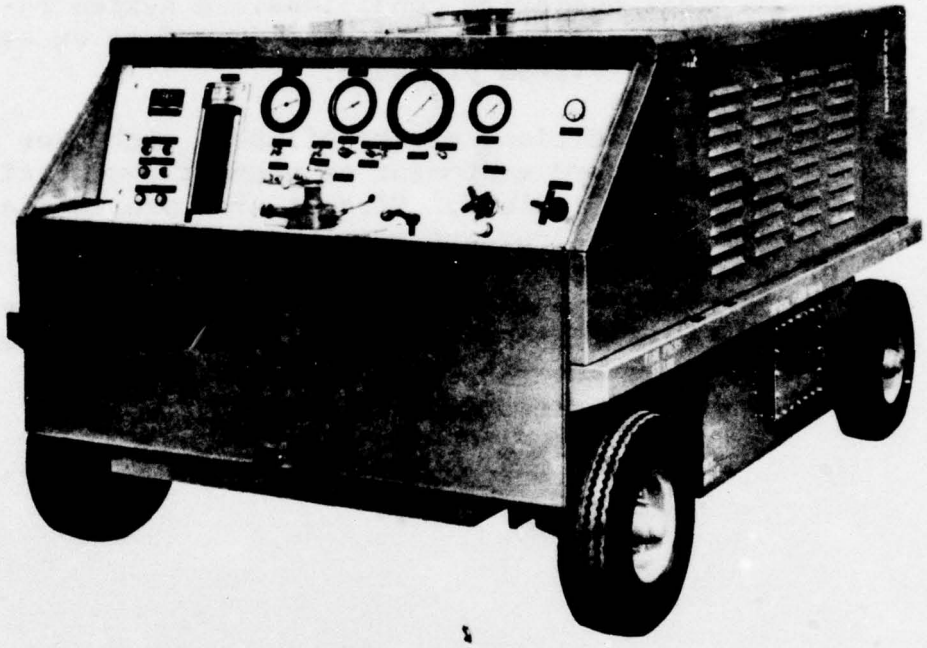


Figure 20-12. Greer Portable Hydraulic Test Machine.

Description: The Greer HPE-8 mobile test stand contains hydraulic circuitry including an independent reservoir to supply required hydraulic fluid; a selector valve permits use of either test machine reservoir or reservoir of system being tested. Fine filtration on both suction and pressure sides of the pump is provided with standard AN type 10 micron filters (or optional 3 microns absolute). Fluid drawn from reservoir and discharged from pump can be directed back

to the suction side of the pump through a bypass valve, or discharged through a shut-off valve to the external pressure port and external hose assembly.

The pumps are variable volume and pressure compensated. Conveniently located manual pump controls provide for infinitely variable adjustment of pressure regulation and fluid flow. A boost pump provides positive boost pressure to main pump under all operating conditions. A system relief valve protects the pump from excessive system pressure.

In addition, air-to-oil heat exchanger is standard equipment to prevent overheating of test fluid. Circuit also provides a thermal cut-out switch.

Instrumentation on the portable machine includes 250 MM flowmeter; 0-6000 PSI pressure guage indicates systems pressure; boost pressure indicated by a 30-inch vacuum to 150 PSI pressure guage. For fluid temperature a 20° - 240°F temperature guage is provided.

Name: Hydraulic System Test and Repair Unit
Developer: U. S. Army Mobility Research and Development Center, Attn: STSFB-RDE-HM, Fort Belvoir, Va. 22060/(703) 664-6713
Model: HSTRU (Prototype Unit) Figure No.: 20-13
Size: 12 ft 3 in L x 5 ft H x 4 ft W Weight: 3000 lbs.
Power Requirements: 110 VAC, 60 Hz, 3.5 KW
National Stock No.:

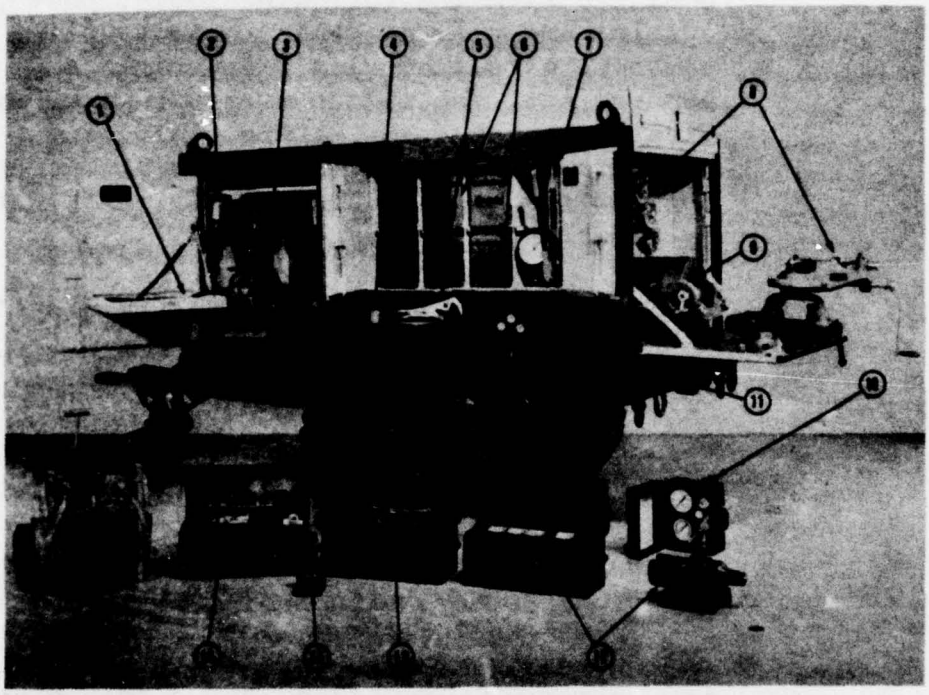


Figure 20-13. U. S. Army MERDC's HSTRU System

Description: The Hydraulic System Test and Repair Unit was designed for test and repair of military construction equipment with the following maintenance capability:

1. Replace hose assemblies
2. Replace or repair tube assemblies
3. Replace seals
4. Broad-range pressure measurement
5. Diagnose system failures (faulty components)
6. Flush and cleanup of system

7. Oil transfer to and from reservoirs and storage containers
8. Solvent washing of components
9. Adaptor kit for attaching test instruments
10. Use with many types and sizes of equipment

To perform the required tasks, the HSTRU is equipped with the following tools: hose cutting and skiving tools, hose coupling assembler, a tube cutting, deburring, and bending set, multirange pressure gage, hydraulic tester (temperature, flow, and pressure), cleaning and flushing equipment, and various support items normally required by a mechanic.

Many of these tools are identified numerically on Figure 20-13 as:

1. Solvent Wash Rack
2. Drop Light
3. Saw, hose cutting
4. Tube Deburring Tool
5. Hose Skiving Tool
6. Tool boxes for tools and spares
7. Hand Pump
8. Tube Bender, with Radins Blocks
9. Hose Coupling Assembler
10. Hydraulic System Tester
11. Multigage, Ranges 0-150, 0-500, 0-5000 psi
12. Tube Flarer with Accessories
13. Hand Tools
14. Tube Cutting Vise
15. Adapter Kit for Tester and Multigage
16. Transfer Pump with Oil Cleaning Element

The hydraulic system tester illustrated (item 10) operates from 50-250°F, 0-100gpm, and 100 - 6000 psi. It is manufactured by Schroeder Brothers Corporation and is described in the portable hydraulic tester section of this chapter.

Name: Type D-5 Portable Hydraulic Test Stand
Manufacturer: Teledyne Sprague Engineering, 19300 So. Vermont Ave., Cardena, Ca. 90248/(213)327-1610
Model: D-5 Figure No.: 20-14
Size: 80 in L x 53 in H x 56 in D Weight: 250 lbs.
Power Requirements: Self-contained

National Stock No.:

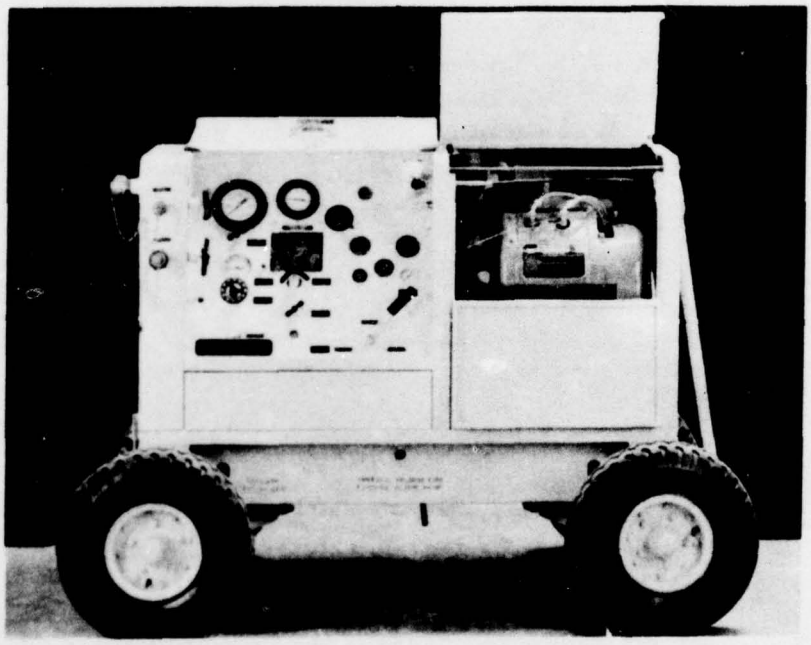


Figure 20-14. Teledyne Sprague's Portable Hydraulic Test Stand

Description: The Model D-5 Portable Hydraulic Test Stand is a self-contained, mobile hydraulic testing unit used to test aircraft hydraulic systems. Its gasoline engine develops 31 HP psi gage pressure. The portable test stand is typically used to perform pressure and integrity test of aircraft hydraulic systems, lines, pumps, etc. Its capability includes the supply of hydraulic

fluid from 0 to 10 GPM at operating pressures from 800 to 5000 psi. The control panel indicates hydraulic pressure, suction pressure and flow.

Name:	Aircraft Power Unit Maintenance Stand
Manufacturer:	Solar, Division of International Harvester Company, 2200 Pacific Highway, P. O. Box 80966, San Diego, Ca. 92138/(714) 238-5500
Model:	P/N 45977-100
Figure No.:	20-15
Size:	86 in L x 38 in W x 62 in H
Weight:	1000 lbs.
Power Requirements:	Self-Contained
National Stock No.:	4920-00-176-9236

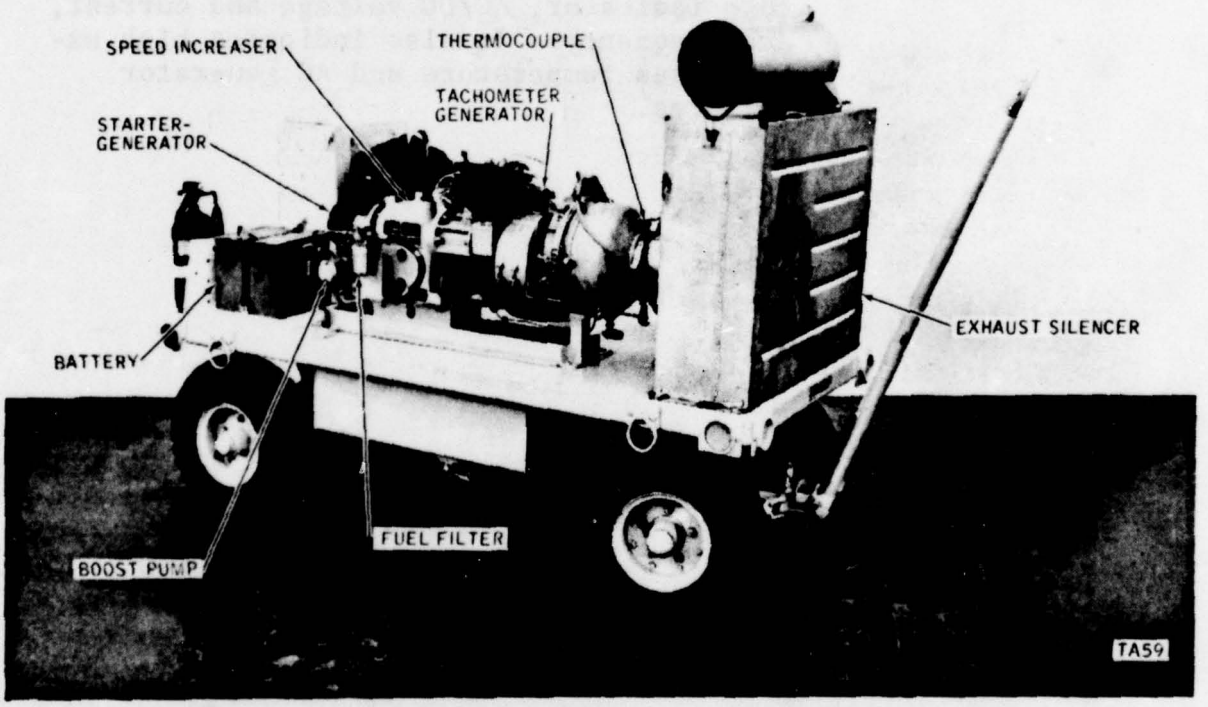


Figure 20-15. Solar APU Mobile Test Stand

Description: The mobile test stand is an open-frame carrier, pivot-plated on two pairs of wheels mounted with pneumatic tires. Mounting provisions for the models T-62T-2, and T-62T-2A auxiliary power units (CH-47 Helicopter) are incorporated together with the necessary electrical and fuel

connections between the unit and the check stand components. The mobile test stand is equipped with a steering towbar and a mechanical hand brake system. It is weatherproofed to provide protection of critical components from the elements. The major assemblies mounted on the test stand are: the battery, control console, thermocouple, tachometer generator, air inlet silencer, exhaust silencer, speed increaser, and the fire extinguisher. The test stand measures engine speed with a tachometer, exhaust gas temperature with a temperature indicator, AC/DC voltage and current, and frequency. It also indicates high exhaust gas temperature and AC generator failures.

Name:	Aircraft Hydraulic System, Gasoline Engine Driven
Manufacturer:	Sun Electric Corporation, 3011 East Route 176, Crystal Lake, Illinois 60014/(815) 459-7700
Model:	AHT-5B
Figure No.:	20-16
Size:	76 in. L x 57 in. W x 53 in. H
Weight:	2200 lbs.
Power Requirements:	N/A
National Stock No.:	4920-710-6669

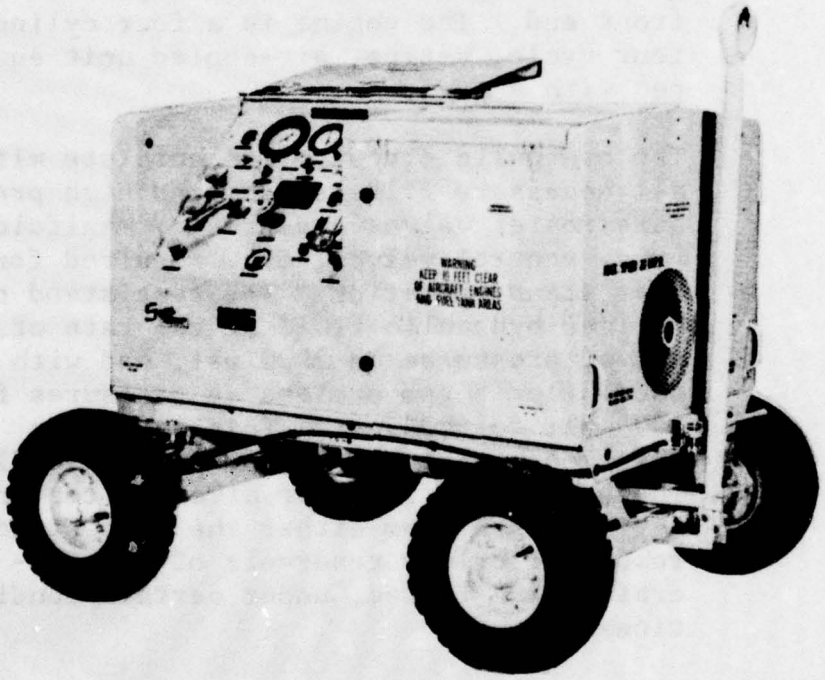


Figure 20-16. Sun Electric's Hydraulic Systems Test Stand.

Description: The Gasoline Engine Driven Hydraulic Systems Test Stand, Sun Electric Corporation Model AHT-5B is used to flush or fill the system with micronically filtered hydraulic fluid, and provide a source of hydraulic pressure for testing aircraft hydraulic systems without the necessity of operating the aircraft engine. All the components of an aircraft hydraulic system may be tested,

including hydraulic systems of aircraft with pressurized reservoir systems.

The test stand is capable of operating under temperature conditions ranging from -29°C(-20°F) to 54°C(130°F). The relative humidity may be 95 to 100 percent at 54°C. The test stand will operate at 6000 feet above sea level. It may be inclined 8-1/2 degrees in any direction from the horizontal.

Power for the test stand is provided by a gasoline engine which is installed at the front end. The engine is a four cylinder, four cycle, V-type, air-cooled unit equipped with a governor.

The hydraulic circuitry is complete with all necessary filters, low and high pressure relief valves, reservoir, manifold, pump, control valves, etc. required for test stand operation. The test stand can deliver hydraulic fluid at the rate of 10 gpm at pressures to 3000 psi, and with reduced flow 5 gpm or less at pressures from 3000 psi to 5000 psi. This rating is based on use of MIL-H-5606 hydraulic fluid. The hydraulic fluid for aircraft testing may be taken from either the test stand reservoir or the reservoir of the aircraft being tested, under certain conditions.

20-2.3 OIL ANALYSIS

The Army Oil Analysis Program (AOAP) is a coordinated Army-wide effort to detect impending equipment component failures through analytical evaluation of oil samples, formerly referred to as the Army Spectrometric Oil Analysis Program (ASOAP).

20-2.3.1 Spectrometric Analysis

Oil analysis in this program is a test or series of tests which provide an indication of equipment condition by applying a method of precision detection and quantitative measurement of wear-metals in an oil sample.

An important part of the premature failure detection system is the spectrometric oil analysis. It is a method of determining the concentration of various chemical elements in oil samples taken from lubricated systems. Based on this concentration of chemical elements the amount of wear metals in the specific sample can be determined. By having knowledge of the metals that are adjacent to wearing surfaces in the component system where the oil sample was taken potential failures are predicted.

The field units take the oil samples from the components (engine, transmission, gear boxes and hydraulic systems), completes the DA 3253 (used oil sample information form) and sends the sample to the laboratory. The laboratory technician removes the History Card (DA 4161 Form) from the files, places it in the spectrometer typewriter, and runs the sample. The analysis results are typed on the form and punched on paper tape. The laboratory evaluator using evaluation criteria determines if the analysis results reveal any potential failure. The paper tape with the analysis results are sent to AVSCOM to be entered in the data bank. At the same time the evaluator makes recommendations to the field units when his evaluation reveals impending failure of a component. A grounding recommendation by an evaluator is accomplished by telephone, followed by a written recommendation.

When the evaluator recommends a removal of a component it is replaced and the suspect sent to an Army depot for teardown analysis. The results of the teardown analysis is sent back to the field unit, the evaluator and AVSCOM.

20-2.3.2 AOAP Objectives

The key elements and goals of the Army program are short response time, improved methods of field sampling, more precise laboratory sample analysis and data evaluations, improved communications, more reliable and accessible data, timely recommendations to the submitting activities, and accurate maintenance feedback for overall effectiveness.

Specific objectives of the Army Oil Analysis Program are:

(1) Enhance aircraft safety of flight by improving the methodology and procedures of detecting impending equipment component failures, extend operational readiness of Army equipment through the efficient and effective use of oil analysis, and to promote the coordination and cooperation of the user.

(2) Reduce maintenance costs through preventive maintenance efforts prior to major repair as indicated by symptomatic techniques.

(3) Attain a twenty-four hour or less response time and three-day response time for nonaeronautical equipment to prevent costly repairs.

(4) Integrate the oil analysis program into the maintenance engineering effort to develop techniques, methods and practices for improving and reducing maintenance costs and expanding the use of oil analysis.

(5) Optimize the interservice exchange of oil analysis support through interservice agreements.

20-2.3.3 Methods of Application

Spectrometric oil analysis is employed as an equipment malfunction/detection aid and, when appropriate, to aid in the development of failure patterns and trends.

Spectrometric analysis is applied to all oil and lubricating fluid-wetted components in Army aircraft.

A uniform calibration standard is used by all Army oil analysis laboratories. Standard forms compatible with the oil analysis data bank are used.

20-2.3.4 Limitations of AOAP

The spectrometric oil analysis method is effective only for those failures which are characterized by an abnormal increase in the wear-metal content of the lubricating oil. Normal detectable failures are:

1. Cylinder damage in reciprocating engines, including worn or broken piston rings and lands, scored or scuffed pistons and cylinder walls, damaged piston pin, plug buttons, broken valve springs, loose or defective valve guides.
2. Worn misaligned or broken anti-friction bearings and retainers.
3. Worn misaligned or scored gears.
4. Worn or scored journal bearing surfaces.
5. Cracked or broken reciprocating engine master rod bearing shells and splines.

Failures which cannot be detected by spectrum analysis are:
1. Failures which occur too rapidly to be detected by oil analysis including failures due to oil starvation and bearing seizure.
2. Failures which proceed from the beginning of failure of a major assembly to a major damage or total failure of the system without a significant increase in metal wear. This category includes most fatigue failures, structural failures and other failures not adjacent to lubricated surfaces.
3. Failures that prior to failure produce wear-metal particles or chips in the 15-20 micron size or larger, the spectrometer will not detect particles this large (normally a 40 micron or larger size particles can be seen without magnification).

20-2.3.5 Oil Analysis Equipment

Test equipment used in oil and fluid analysis includes fluid analysis spectrometers, ferrograph analyzers, viscosity meters and particle counters. A sampling of these primarily laboratory instruments follows. It should also be noted that in-line particle counters and ferrograph analyzers are being developed and tested and may become a part of future hydraulic and engine systems (aircraft, etc.)

Name:	FAS-2 Fluid Analysis Spectrometer
Manufacturer:	Baird-Atomic, Inc., 125 Middlesex Turnpike, Bedford, Ma. 01730/(617) 276-6120
Model:	A/E 35U-3 Figure No.: 20-17
Size:	63 in L x 57 in H x 42 in W Weight: 500 lbs.
Power Requirements:	120, 208, 240 and 416 VAC, 50/60 Hertz, Single Phase
National Stock No.:	6650-00-251-0712

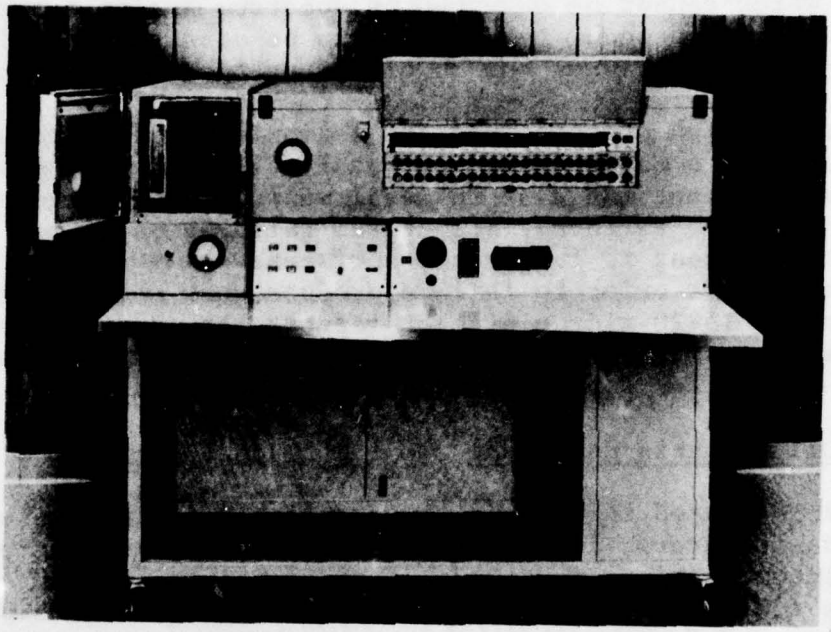


Figure 20-17. Baird-Atomic Fluid Analysis Spectrometer.

Description: The FAS-2 is the basic instrument in an analytical technique applicable to any oil-wetted mechanism. Moving contract between metallic components is always accompanied by friction and the consequent wearing away of the surfaces in contact. The metals worn off remain in the lubricant, and can be used to provide accurate information regarding the mechanism's condition and operation. Simply stated, the quantity of metal indicates the severity

of wear, and the type of metal identifies the faulty component. (Hence the advantage of 20- element spectroscopic analysis vs. non-specific particle monitoring.) Once normal wear patterns are established, deviations from them can be easily detected and corrective action taken.

The FAS-2 spectrometer performs five basic functions:

- Exitation of impurity atoms to convert them to radiant energy
- Optical processing that includes collection, dispersion, reimaging, and detection of element radiant energy, and the conversion of the radiant energy to electrical energy.
- Electronic processing that includes measuring the electrical energy and processing the measured values into a form suitable for driving a display device.
- Displaying the measured values in a form tailored to the operator's needs.
- Generating sufficient electrical power to operate all components.

The instrument also contains an internal diagnostic system providing the operator with a tool to quickly and efficiently determine if the spectrometer is operating correctly. This system also provides data to assist in troubleshooting and often enables the experienced maintenance man to pinpoint a fault down to the defective component.

Name:	Duplex Ferrograph Analyzer
Manufacturer:	Foxboro/Trans-Sonics, Inc., P. O. Box 435, Burlington, Ma. 01803/(617)272-1000
Model:	7069 Figure No.: 20-18
Size:	18 in W x 18 in D x 29 in H Weight: 77 lbs.
Power Requirements:	115 VAC, 60 Hz
National Stock No.:	

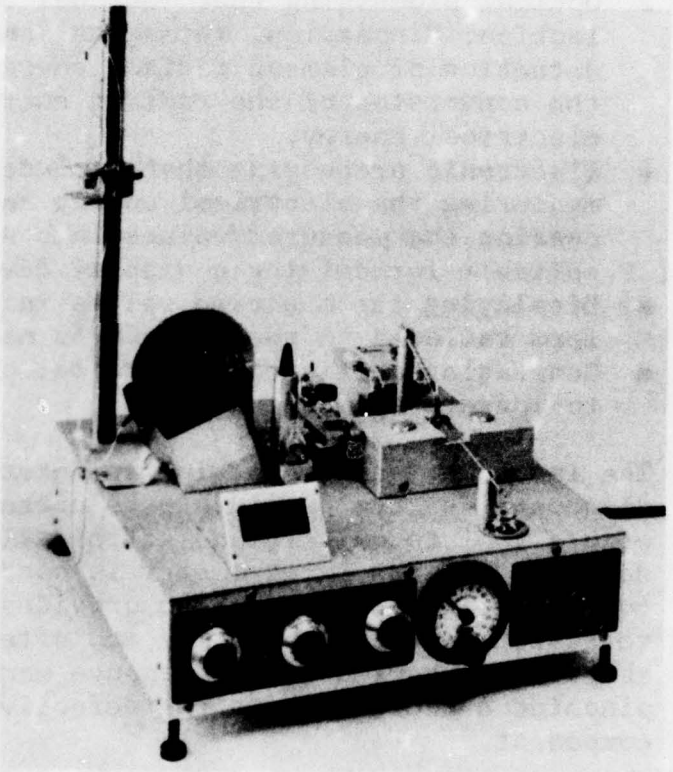


Figure 20-18. Foxboro/Trans-Sonics' Duplex Ferrograph Analyzer.

Description: The Ferrograph uses a technique developed to separate wear debris and contaminant particles from a lubricant, and to arrange them on a transparent substrate for examination. As the wear particles are precipitated magnetically, virtually all the

the unwanted carbon dirt particles are eliminated. The precipitated particles, deposited according to size, may be individually examined since large particles are not obscured by agglomerates of smaller particles, and the unique characteristics of all sizes of particles can be established.

The Duplex Ferrograph analyzer (Figure 20-18) consists of two particle separators: on the right is a standard Ferrograph analyzer, and on the left a Direct Reading (DR) Ferrograph.

The standard Ferrograph analyzer consists of a pump to deliver the lubricant sample at a flow rate of the order of 0.25 ml per minute, a magnet that develops a high-gradient magnetic field near its poles, and a treated transparent substrate on which the particles are deposited. The lubricant sample, diluted with a special solvent to promote the precipitation of wear particles, is pumped across the transparent substrate which is mounted at a slight incline. The magnetic particles adhere to the substrate, distributed according to size. After about 2 ml of oil have been pumped across the slide, a washing and fixing cycle removes the residual oil and causes the wear particles to adhere permanently to the slide. Using the Ferrogram reader attached to a bichromatic microscope, the optical densities of the deposits may be observed at various distances along the Ferrograms to determine the percentage area covered, and thus the amount and particle size distribution.

With the Direct Reading section of the Duplex Ferrograph, 1 ml of lubricant is syphoned through the precipitation tube and the optical densities of the deposits at selected distances are observed.

When successive lubricant samples yield ferrograms with essentially constant density readings, it may be concluded that the machine is operating normally and producing wear particles, and in particular in the ratio of large to small particles, indicates the initiation of a more severe wear process.

Information on the morphology of the deposited particles is obtained with the aid of a birchromatic microscope which uses simultaneously reflected red light and transmitted green light. Metal particles as small as 1 um reflect red light and block green light and thus appear red. Particles composed of compounds allow much of the green light to pass and appear green or, if they are relatively thick, yellow or pink.

Particles generated by different wear mechanisms have characteristics which can be identified with the specific wear mechanisms. Rubbing wear particles found in the lubricant of most machines have the form of platelets and indicate normal permissible wear. Cutting or abrasive wear particles take the form of minature spirals, loops, and bent wires similar to swarf from a machining operation. A concentration of such particles is indicative of a severe, abrasive wear process; a sudden increase in the concentration of such particles in successive lubricant samples signals imminent machine failure. Particles consisting of compounds can result from an oxidizing or corrosive environment. Steel spherical particles are a characteristic feature associated with fatigue crack propagation in rolling contacts. The concentration of spherical particles indicates the extent of crack propagation.

Name: Oil Monitor (Gas Turbine Engine)
Manufacturer: General Electric Company, Aircraft Engine Group, 1000 Western Avenue, Lynn, Ma. 01910/(617)594-0100
Model: T700 Prototype Figure No.: 20-19
Size: Weight:

Power Requirements: 115 VAC, 400 Hz
National Stock No.:

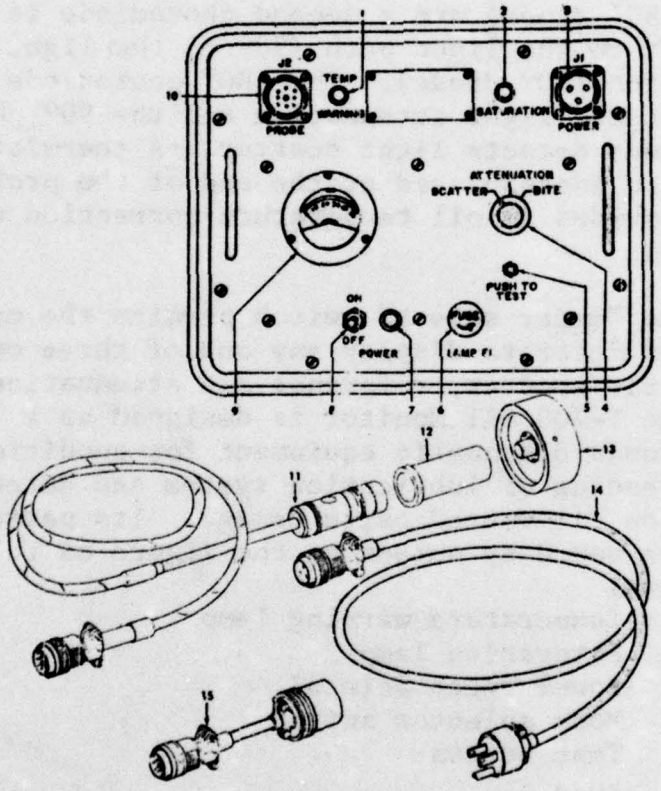


Figure 20-19. GE's T-700 Prototype Oil Monitor.

Description: The T700 Oil Monitor is a solid-state system that measures and displays the attenuation and the scatter from an infrared light beam. The beam is generated by a solid-state lamp which is immersed in the medium

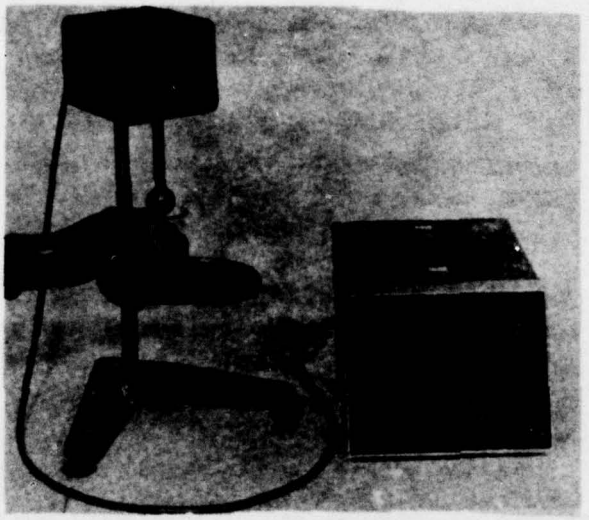
to be tested for contamination. The amount of light which is scattered by suspended particles is related to the particlulate contamination. The attenuation of the light beam is related to the chemical degradation of the oil.

Two photodiodes are encapsulated with the solid-state lamp at the end of a probe in a semi-circular arrangement. One photodiode is directly opposite the light source (180° diode) and a second photodiode is at 90° to the light path (90° to the light patch (90° diode). The 180° photodiode detects light attenuation and the 90° photodiode detects light scatter. A thermistor, also encapsulated at the end of the probe, provides an oil temperature correction signal.

The "meter select" switch permits the monitor meter to display any one of three outputs: scatter, reference and attenuation. The T-700 Oil Monitor is designed as a ground diagnostic equipment for condition trending of lubrication system and detection oil-wetted parts damage. Its parts are noted by number on the figure as fol lows:

1. Temperature warning lamp
2. Saturation lamp
3. Power receptacle J1
4. Mode selector switch
5. Test button
6. Fuse
7. Power lamp
8. Power switch
9. Gage
10. Probe receptacle J2
11. Probe and cable assembly
12. Sleeve
13. Baseplate
14. Power cable
15. Airframe adapter cable

Name:	Viscometer
Manufacturer:	Nametre Company, 272 Loring Avenue, Edison, N. J. 08817/(201)985-5659
Model:	7.006 Figure No.: 20-20
Size:	Control Unit -7 in H x 8.5 in W x 12 in D Weight:
Power Requirements:	105-125 VAC, 50-60 Hertz, 7 Watts
National Stock No.:	



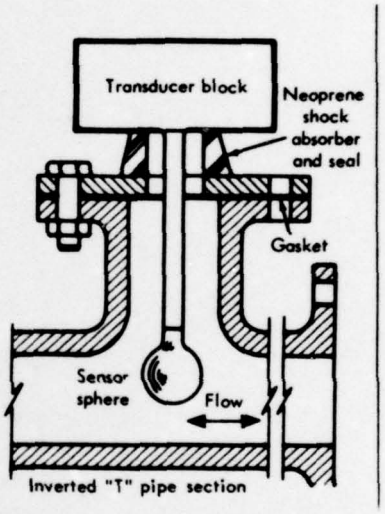


Figure 20-20. Nametre Viscometer and On-Line Arrangement.

Description: The Viscometer utilizes continuous control of the amplitude of low frequency shear waves generated by a small immersed stainless steel sphere to measure viscosity. The oscillating torsional pendulum technique provides a stable and accurate instrument capable of measuring viscosities in less than one minute per sample (1 to 30 ml as well as much larger quantities of flowing liquids) of gasoline, oil, suspensions, asphalt, starch, polymers, blood and metals to high accuracy over the wide range of 0 to 100,000 centipoises.

The Viscometer is available in models for laboratory use, in-line process control (Figure 20-20) and controlled dry bath.

The measurement is affected neither by large solid particles in the fluid nor by rapid flow around the sensing tip, thus making the instrument an on-line candidate. However, certain degree of temperature stability must be present for accurate results.

Name:	Particle Counter Mainframe with Sensor
Manufacturer:	Royco Instruments, Inc., 141 Jefferson Drive, Menlo Park, Ca. 94025/(415)325-7811
Model:	345/366 Figure No.: 20-21
Size:	17 in W x 8.5 in H x 17 in D Weight: 47 lbs.
Power Requirements:	115/230 VAC, 50/60 Hertz, 65 Watts
National Stock No.:	

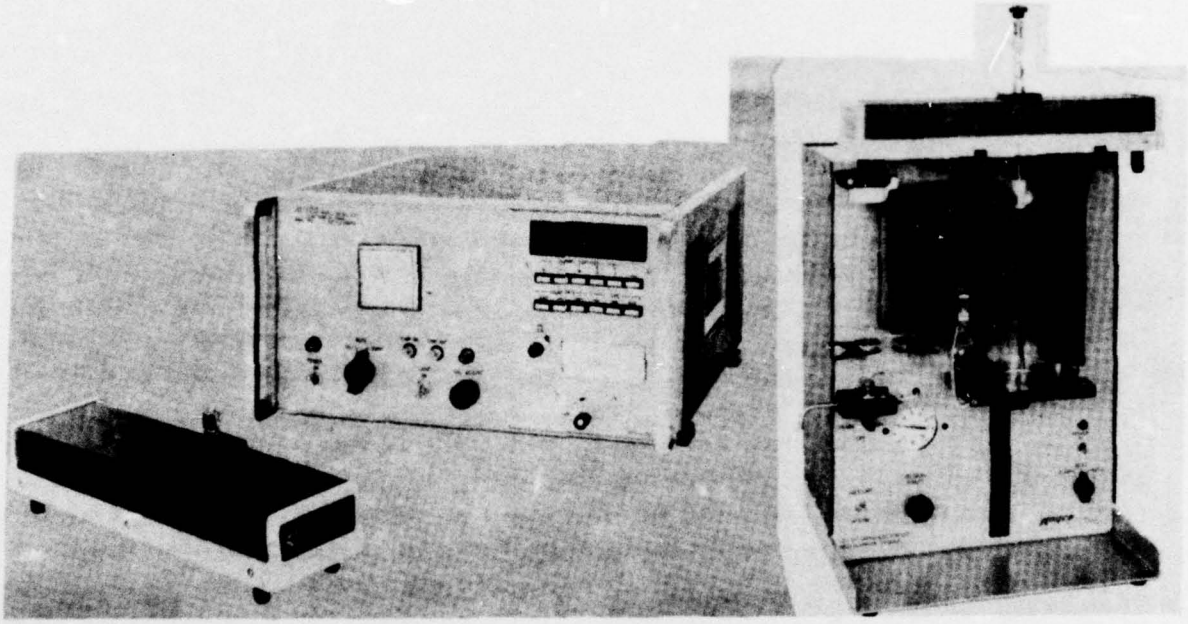


Figure 20-21. Royco Particle Counter and Liquid Sample Feeder.

Description: The Royco Model 345 Particle Counter is designed for simultaneous, automatic particle counting in multiple size ranges. The basic mainframe accepts interchangeable plug-in modules and is equipped with a removable sensor and power supply. The sensor may be plumbed directly into the liquid line or adapted for batch sampling. The sensor cells are available in stainless steel with sapphire windows for resistance

to corrosion. The Model 345 utilizes a light absorption/total scatter optical system. Standard particle size sensitivity is 5 micros at a sample flow rate of 100 ml per minute. An optional 2 micro sensitivity is available.

Name: "Criterion" Particle Counting and Sizing Analyses System

Manufacturer: HIAC Instruments Division, Pacific Scientific Company, P. O. Box 3007, 4719 W. Brooke St., Montclair, Ca. 91763/(714)621-3965

Model: PC 320 Figure No.: 20-22

Size: 18 in W x 9.5 in H x 18 in D Weight: 130 lbs (total)

Bottle Sampler: 12 W x 3 ft H x 2 ft

Pump: 6 in x 6 in H x 6 in D

Power Requirements: 110-120 VAC, 60 Hertz

National Stock No.:

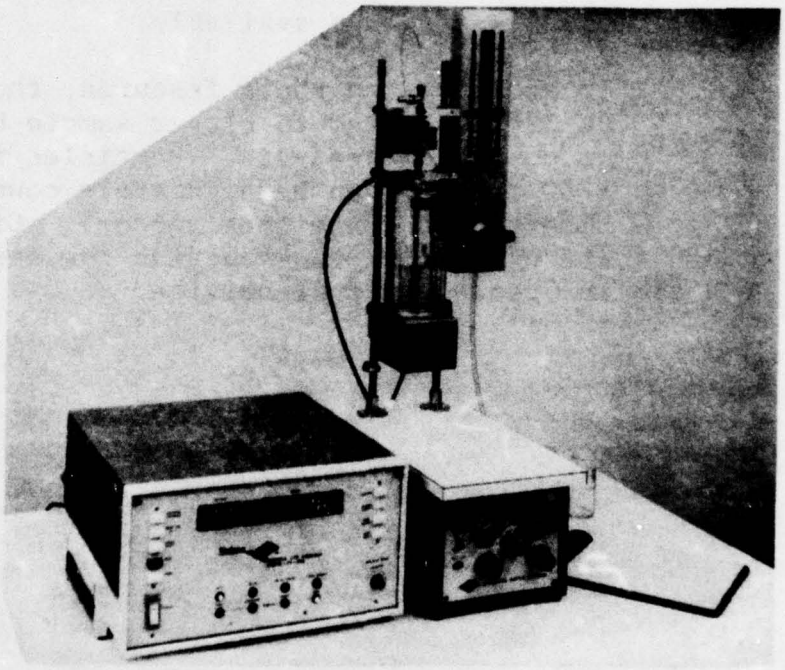


Figure 20-22. HIAC "Criterion" Particle Counter and Sampling System.

Description: The PC 320 "Criterion" particle size analyzer automatically measures particles by size and counts them (in as many as twelve different size groups). It will operate with full efficiency on liquids of different optical density and color without

any special adjustment. In addition it has an integral indicator which warns of any change in sensor operation due to partial window blockage or change in the fluid system.

The "Criterion" analyzer has a BCD output which will interconnect with data processing equipment or for analog accessories. Sensors are compact (2" x 2" x 5") with ultra linear calibration. Sensors can be located as far as 1000 feet from the counter if necessary. In addition, multiple sensors with selector switch can be used. Special sensors for use with corrosive liquids are also available.

In addition, to these features, the Model PC 320 is suited to either sample bottle or on-stream analysis. Particles from 1 to 9000 microns can be accurately counted and sized (with the proper sensor). Circuits are of modular construction for easy "plug-in" replacement or service.

Name:	Prototron Particle Counter
Manufacturer:	Spectrex Company, 3594 Haven Avenue, Redwood City, Ca. 94063/(415)365-6567
Model:	ILI 1000 Figure No.: 20-23
Size:	12 in W x 18 in H x 24 in D Weight: 31 lbs.
Power Requirements:	115 VAC, 60 Hertz
National Stock No.:	

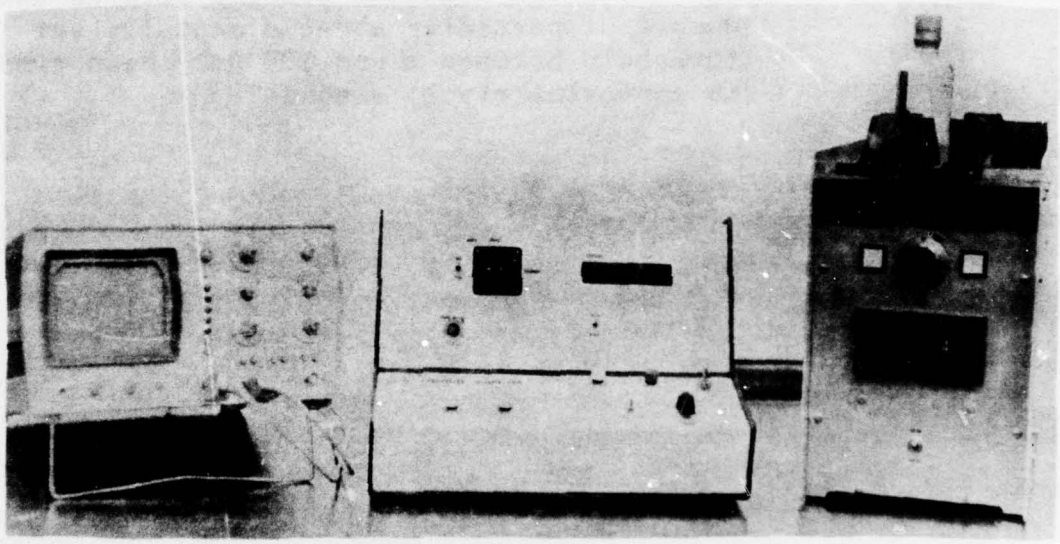


Figure 20-23. Spectrex Prototron Particle Counter.

Description: The Model ILI 1000 In-Situ Liquid Inspection Station or Prototron Particle Counter is designed to permit thorough inspection of bottle liquids without breaking any seal or removing any of the contained liquid. Visual observation of large tramp solids is assisted by diffuse vertical illumination. A laser beam is provided to permit observation of small particles by near-forward light scatter. In addition, a scanning and detection system is provided to

automatically quantify the number of small particles in one milliliter of the contained liquid.

A variable threshold is provided so that quality control levels may be established against which individual samples may be compared. Electrical outputs are available so that sample cleanliness may be observed with an oscilloscope and digital outputs are provided for printer or computer interfacing.

The Prototron Particle Counter detects the number of particles above a manually set threshold between 1 and 100 μm. Scan time is approximately 15 seconds.

Name: Oil Quality Analyzer
Manufacturer: Northern Instruments, Inc., 6680 N. Highway 49, Lino Lakes, Minnesota 55014/(612) 784-1250
Model: NI-1A
Figure No.: 20-24
Size: 4 in H x 9.5 in L x 5 in. W.
Weight: 29.5 oz.
Power Requirements: 5.6 Volt Battery
National Stock No.:

Figure 20-24. Northern Instruments' Oil Quality Analyzer.

Description: The NI-1A Oil Quality Analyzer provides a relative measure of the change in quality of the oil sampled. As such, it is useful primarily as a screening instrument. The

heart of the Oil Quality Analyzer is a sensor system based on thin film technology. Because the sensor measures the electrochemical properties of the moleculte itself, it senses changes in the different types of contaminants. Durable solid state circuitry is combined with the rugged ABS plastic case, making the NI-1A a valuable field tool as well as a laboratory instrument. Changes in oxidation, acids, water, antifreeze, and fuel, are claimed by the manufacturer.

The NI-1A instrument contains a built-in sensor cavity which is used to hold a few drops of the oil sample. Calibration of the Oil Quality Analyzer is required once a day providing that only one type of oil is to be analyzed. Otherwise, additional calibration is required for each oil brand or type sampled. The NI-1A Analyzer will show changes in oil breakdown contamination and oil oxidation. The presence of contamination can be found through comparison testing. In this manner, contamination sensed can be due to metal particles, soot, dirt, sludge and other solids. The battery is rated to handle 5000 tests.

20-2.4 PORTABLE HYDRAULIC SYSTEM TESTERS

Name:	Portable Hydraulic Circuit Tester
Manufacturer:	Schroeder Brothers Corporation, Nichol Ave., Box 72, McKees Rocks, Pa. 15136/(412)771-4810
Model:	PHT-100-3 Figure No.: 20-25
Size:	9 in L x 11 in W x 6.5 in H Weight: 24 lbs.
Power Requirements:	N/A
National Stock No.:	4910-00-065-5296(similar model)

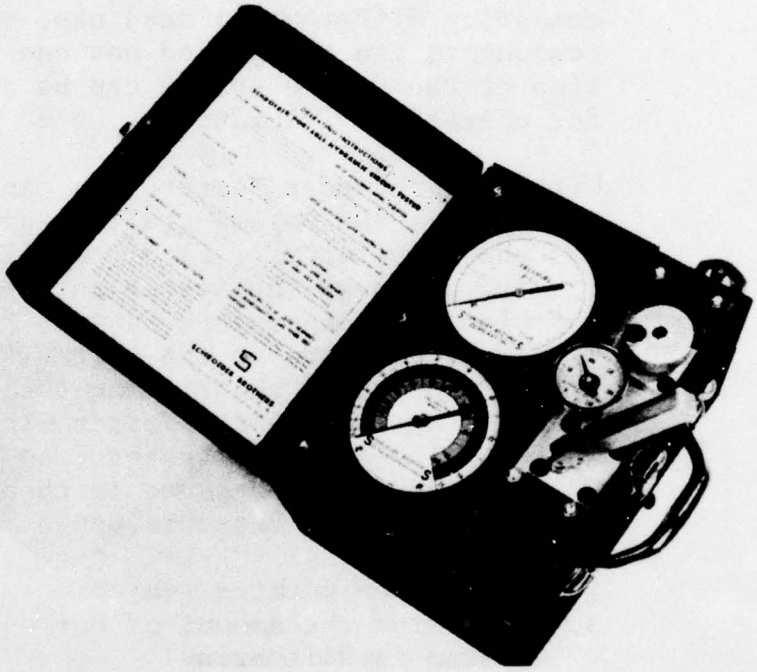


Figure 20-25. Schroeder's Portable Hydraulic Circuit Tester.

Description: The Schroeder PHT-100-3 Tester employs the fixed, sharp-edge orifice method of measuring flow. This assures accurate gallon-per-minute readings even with the wide range of oil temperature and viscosity changes common to hydraulic systems. Multiple scales are provided to give exact GPM readings at both high and low ranges - increments are as low as 1/4 GPM. The volume range selector permits the operator to quickly change to the desired scale.

There is no need to remove individual components from the system for visual and mechanical checking...just connect the Tester into the pressure line of the pump and let it do the checking for you. The principle is simple - pump efficiency can be checked in a matter of minutes by determining the differential in flow under "no load" and "operating load" conditions at operating temperatures. By installing a "tee" in the pump pressure line and comparing differential readings, other components can be checked out one at a time or the entire system can be analyzed for operating efficiency.

With the Schroeder Tester, you can:

1. Measure the volume (gallons per minute) and temperature (^{o}F) of the fluid passing through the system on the Tester's Flow and Temperature Gauges;
2. Apply pressure to the system and its components by restricting the fluid passing through the Tester with the manually-operated Tester Load Valve. The resultant pressure is then read on the Tester Pressure Gauge.

This data then permits you to:

3. Determine the amount of horsepower the system is delivering.
4. Determine which component in the system, if any, that is not working properly.

Model PHT-100-3 has the following capability:
100 GPM flow gauge with 3 scale ranges: 3-14 GPM; 8-36 GPM; 24-100 GPM. 250°F temperature gauge; 3000 psi pressure gauge. It comes with 1 in. NPSM Female Swivel parting.

Name:	Flo-check PFM2 Universal Hydraulic Test Unit
Manufacturer:	Flo-tech, Inc., 403 S. Washington Blvd., Mundelein, Illinois 60060/(312)566-9120
Model:	PFM2-50 Figure No.: 20-26
Size:	10 in x 8 in x 7.75 in Weight: 15 lbs.
Power Requirements:	pen light mercury cells
National Stock No.:	

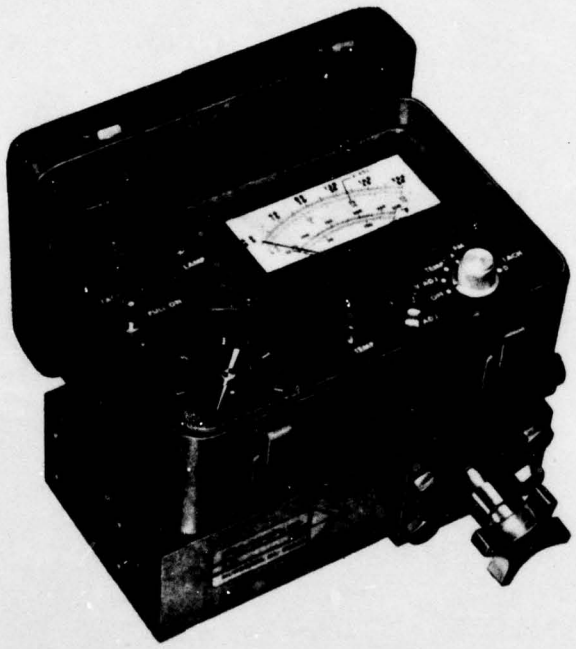


Figure 20-26. Flo-Tech's Flo-check Portable Hydraulic Test Unit.

Description: The PFM2 has been designed to take all measurements simultaneously for fast, efficient trouble-shooting. It displays readings from within the test unit, or can be switched instantly to remote sensors for GPM, RPM, or temperature ratings. The sensors can be used even when no hydraulic tests are being performed.

The PFM2 unit features:

- Turbine flow meter
- Rugged, dual scale 5" meter

- Electric thermistor thermometer - 3 seconds response
- Completely self-contained/automatic battery shut-off
- Back pressure to 5000 psi

Name:	Portable Hydraulic Flow Monitoring System
Manufacturer:	Kenett Corporation, 275 Needham Street, Newton, Ma. 02164/(617)969-7260
Model:	KT-FLO-50 Figure No.: 20-27
Size:	12 in L x 12 in W x 8 in H Weight: 20 lbs.
Power Requirements:	N/A
National Stock No.:	

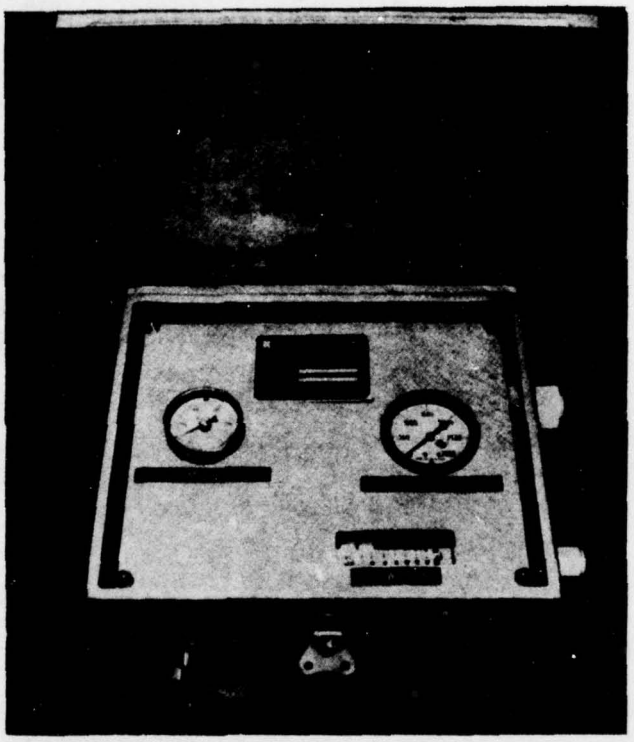


Figure 20-27. Kenett's Portable Hydraulic Flow Monitoring System.

Description: The Kenett portable hydraulic flow monitoring system accurately measures fluid flow rates, including pressure and temperature, to determine the efficiency of pump performance, flow regulator settings and/or hydraulic system performance. It is ideal for use in industrial and/or mobile oil hydraulic circuits as well as in lubrication, coolant and transfer lines.

The flow meter is designed for temporary

installations by the serviceman doing system checkout or trouble shooting. It can be applied to pressure lines, return or drain lines and will measure pressure up to 3000 psi, as well as temperature ranging from 50-300°F.

A moving indicator on the meter provides direct reading, thereby eliminating the need for electrical connections or readout devices. Because a sharp-edged, fix orifice is used to make measurements, the system is relatively immune to viscosity change.

The flow meter is calibrated for general purpose use with hydraulic fluids having a specific gravity of .84. Fluids with other specific gravities can also be measured by utilizing pre-determined correction factors.

Model KT-FLO-50 handles 5-50 GPM, 0-3000 psi pressures, 50-300°F temperatures, and has a 1.25 in. port size.

Name: Flow Meter, Flow Pressure Test Kit
Manufacturer: Hedland Products, Division of Racine, Federated, Inc., 2200 South St., Racine, Wisconsin 53404 (414)639-6770
Model: 701(3/4 in. pipe thread) Figure No.: 20-28
Size: 3/4 in. pipe Weight:
Power Requirements: N/A
National Stock No.:

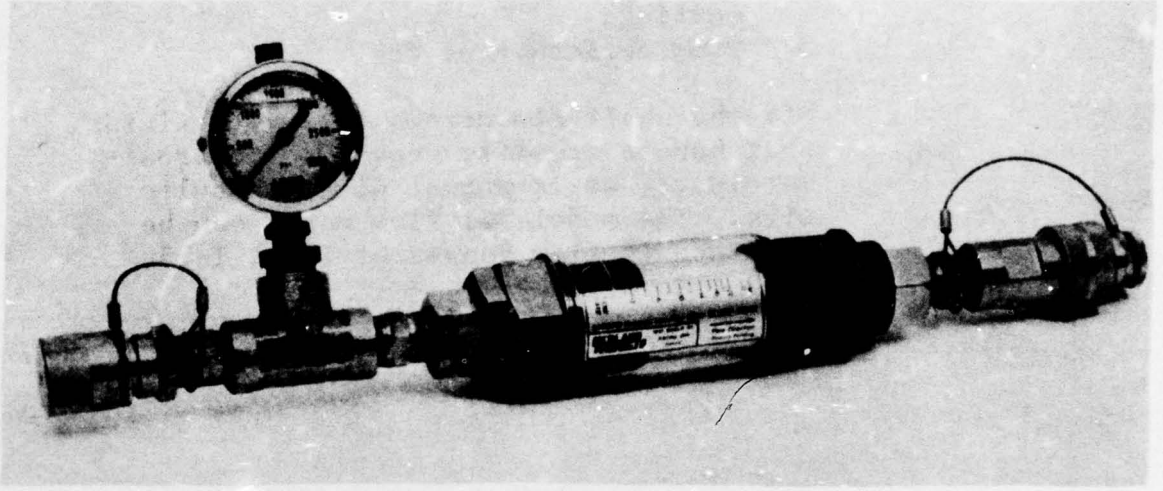


Figure 20-28. Hedland's Flow Meter Used as Part of Test Kit.

Description: The Hedland direct reading flow-meter monitors fluid flow rates to determine pump performance, flow regulator settings, or hydraulic system performance. It is intended for use in mobile or industrial oil hydraulic circuits as well as in lubrication, coolant or transfer lines.

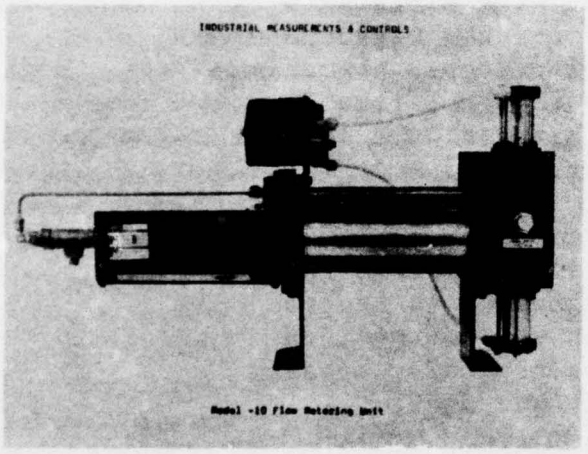
A moving indicator on the meter provides direct reading and eliminates any need for electrical connections or readout devices. Meters are available in 1/2", 3/4", or 1-1/4" pipe or tube sizes, with scales ranging from 1/2 - 5 GPM, up to 10 - 100 GPM. Scales can also be calibrated in RPM, FPM, or other increments.

Combined with a pressure gauge as shown in Figure 20-28, and coupled into a pressure line, it can be used to determine:

1. Maximum-minimum GPM of pump depending on RPM of engine.
2. Free flow or operating pressure to a hydraulic attachment
3. Proper engine speed setting for correct flow
4. Proper pressure relief or flow valve settings
5. Pump performance, etc.

Off-the-shelf flowmeters work with fluids that have a specific gravity of approximately .84 as is normal with hydraulic oils. The model 701 flow meter can be obtained in flow ranges of 1-10, 1-15, 1-20, and 2-30 GPM.

Name: Positive Displacement Flowmeter (PDQmeter)
Manufacturer: Industrial Measurements and Controls, Div. of International Rectifier Corp., 451 West Covina Blvd., San Dimas, California 91773/ (714)599-1204
Model: 410(Readout Control) Figure No.: 20-29
Size: 9 in W x 13 in L x 11.5 in H Weight: 18 lbs.
Power Requirements: 115 VAC, 60 Hz, low pressure shop air.
National Stock No.:



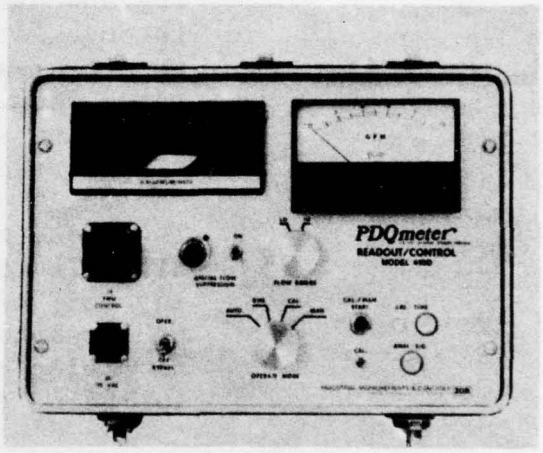


Figure 20-29. Industrial Measurements and Controls PDQmeter.

Description: The PDQmeter is an extremely accurate hydraulic fluid-rate measuring system for shop or laboratory use. High accuracy and repeatability are assured over a wide range of fluid pressures, flow rates, and temperatures. The PDQmeter consists of a Readout Control Unit housed in a portable carrying case and a Flow Metering Unit. These units are interconnected by an electrical cable. (Figure 20-29.) The RCU contains

the majority of the electronic control circuits for the system and provides all operator controls including two flow-rate meters for visual monitoring of flow. The FMU is the electrohydraulic portion of the system that is subjected to the actual hydraulic fluid flow and converts the flow rate into an electrical analog signal. In addition, certain electronic circuits are mounted on the FMU in a junction box.

The FMU is a precision metering cylinder designed for high pressure (3000 or 5000 psig) operation. A special four-way flow-reversing valve ensures continuous monitoring and measurement. The fluid path through the unit limits the pressure drop to a near-zero level ... even at maximum rated flow. Within the FMU, flow is converted to electric signals by a special linear velocity transducer.

The probe of the transducer is coupled directly to the cylinder piston; the sensing coil of the transducer is exposed only to atmospheric pressure; the cylinder has no moving high pressure seals or parts subjected to significant wear.

The unique four-way flow-reversing valve is controlled from the RCU; the valve reverses the flow path in the cylinder as the piston approaches the limit of its stroke in either direction. Operating power for the valve is provided by low pressure shop air (40-60 psig). Valve reversal time is approximately 0.1 second and except for this momentary interval, the valve remains in a dormant condition. The "open-center" valve design ensures unrestricted flow during valve reversals. The velocity transducer signal from the FMU is applied to the RCU and converted to a multi-scaled digital display.

Name: Hydraulic System Test Set

Manufacturer: Boeing Helicopters, Boeing Vertol Company, P. O. Box 16858, Philadelphia, Pa. 19142 / (215)522-7500

Model: Part #114G1038-71 Figure No.: 20-30

Size: 31 in L x 20 in W x 14.5 in H Weight: 25 lbs.

Power Requirements: 115/208 VAC, 400 Hz, 3 Phase; 28 VDC

National Stock No.:

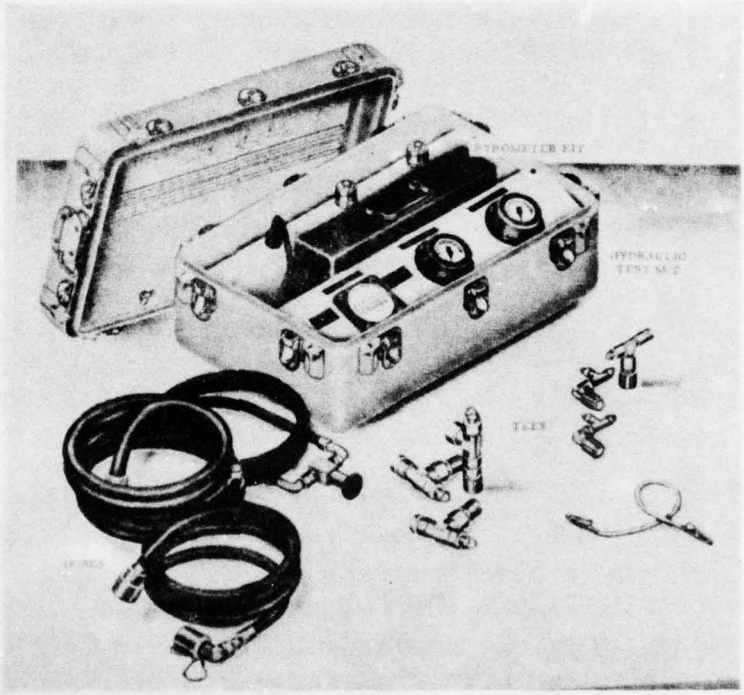


Figure 20-30. Boeing Helicopter's CH-47 Hydraulic Test Set.

Description: The Hydraulic System Test Set provides equipment for testing and troubleshooting the flight control and utility hydraulic systems of the CH-47 helicopter. The equipment is used to make pressure, temperature, and frequency measurements outlined in the TM 55-1520-209/227-20 maintenance manual. Various tee connectors included in the test set provide quick-disconnect test points on helicopters without permanent test connectors.

AD-A040 129 RCA GOVERNMENT SYSTEMS DIV BURLINGTON MASS AUTOMATED--ETC F/G 15/5
TEST ACCESSIBILITY DESIGN GUIDE FOR ARMY MECHANICAL, HYDRAULIC --ETC(U)
SEP 76 F W HOHN, K G HOPKINS, R C BLANCHARD DAAA25-75-C-0681
UNCLASSIFIED FA-FCF-10-76 NL

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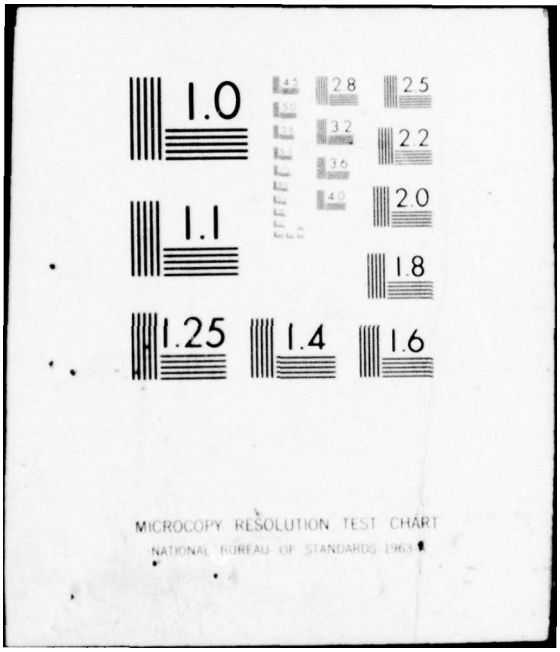
1.0
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4.5
5.0
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

Name: Hydraulic System Test Set
Manufacturer: Boeing Helicopters, Boeing Vertol Company, P. O. Box 16858, Philadelphia, Pa. 19142 / (215)522-7500
Model: Part #114G1038-71 Figure No.: 20-30
Size: 31 in L x 20 in W x 14.5 in H Weight: 25 lbs.
Power Requirements: 115/208 VAC, 400 Hz, 3 Phase; 28 VDC
National Stock No.:

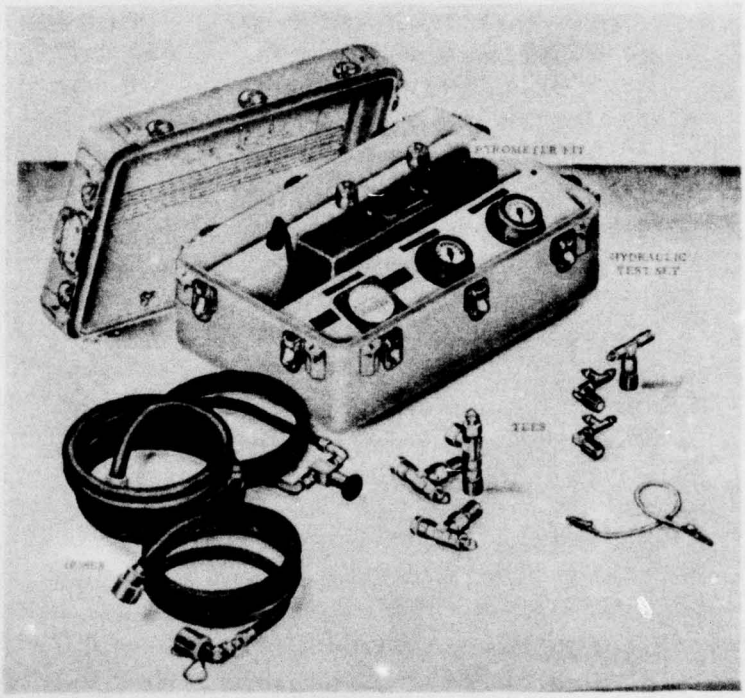


Figure 20-30. Boeing Helicopter's CH-47 Hydraulic Test Set.

Description: The Hydraulic System Test Set provides equipment for testing and troubleshooting the flight control and utility hydraulic systems of the CH-47 helicopter. The equipment is used to make pressure, temperature, and frequency measurements outlined in the TM 55-1520-209/227-20 maintenance manual. Various tee connectors included in the test set provide quick-disconnect test points on helicopters without permanent test connectors.

The test set consists of two pressure gauges (0-5000 psi and 0-10000 psi), a reed-type frequency meter (200-300 Hz), a pyrometer kit (0-400 degrees F.), several tee connectors, hose assemblies and a jumper cable.

20-2.5 LEAK TESTERS AND MONITORS

Name:	Leak Rate Monitor	
Manufacturer:	Volumetrics, 1025 West Arbor Vitae, Inglewood, Ca. 90301/(213)641-3747	
Model:	14321	Figure No.: 20-31
Size:	20 in W x 11 in H x 20 in D	Weight: 47 lbs.
Power Requirements:	110 VAC, 60 Hz	
National Stock No.:		

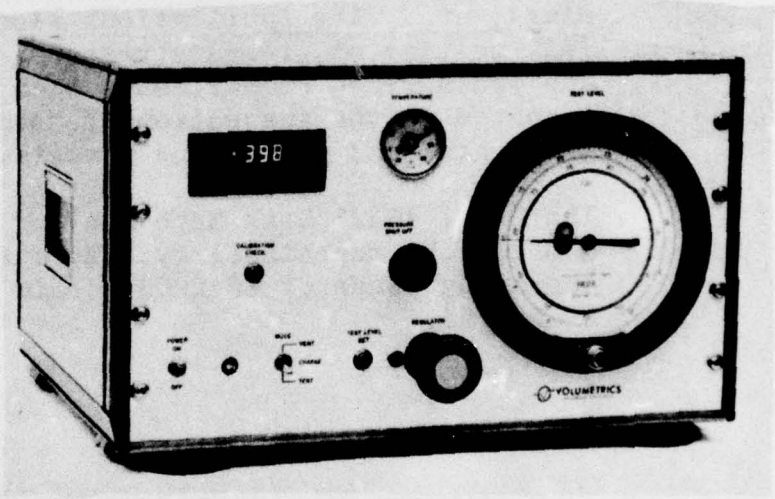


Figure 20-31. Volumetrics' Leak Rate Monitor.

Description: The Volumetrics Model 14321 Leak Rate Monitor is designed for fast, accurate indication of leakage rates of all types of pressure components of which actual leak rates must be known. By use of a broad range, high accuracy, solid state, digital flow indicator, combined with an integral flow regulator, and pressure indicator, the Volumetrics Model 14321 provides in one compact, portable unit a complete ready to use system for performing leak rate measurements. The only additional equipment required is a pressure source (instrument air or nitrogen) and a means of

connecting the leak rate monitor to the test unit. Once the system, including the unit under test is pressurized to the desired level, a "MODE" switch is actuated from "CHARGE" to "TEST". Indication of leak rate is immediately displayed in standard engineering units. A "CALIBRATE" mode provides for easy means of verifying the accuracy of the flow monitor by use of an integral "standard leak rate" orifice.

The Leak Rate Monitor measures leakage of components such as valves, access locks, electrical penetrations, O-ring seals, plugs, etc. Its applications also include leak testing of pressure vessels, chambers and pressurized compartments such as is required in the inspection of holding tanks, tank cars, and processing vessels.

The Model 14321 Leak Rate Monitor has a $\pm$ o.2% F.S. repeatability. It has a usable operating range of 20-2000 cc/min flow and 0-100 psi.

Name: Pressure Decay Leak Tester
Manufacturer: Uson Corporation, 4120 Directors Row, Houston, Texas 77018/(713)686-9421
Model: 310 Figure No.: 20-32
Size: 8 in H x 8 in W x 15 in D Weight: 15 lbs.
Power Requirements: 115 VAC
National Stock No.:

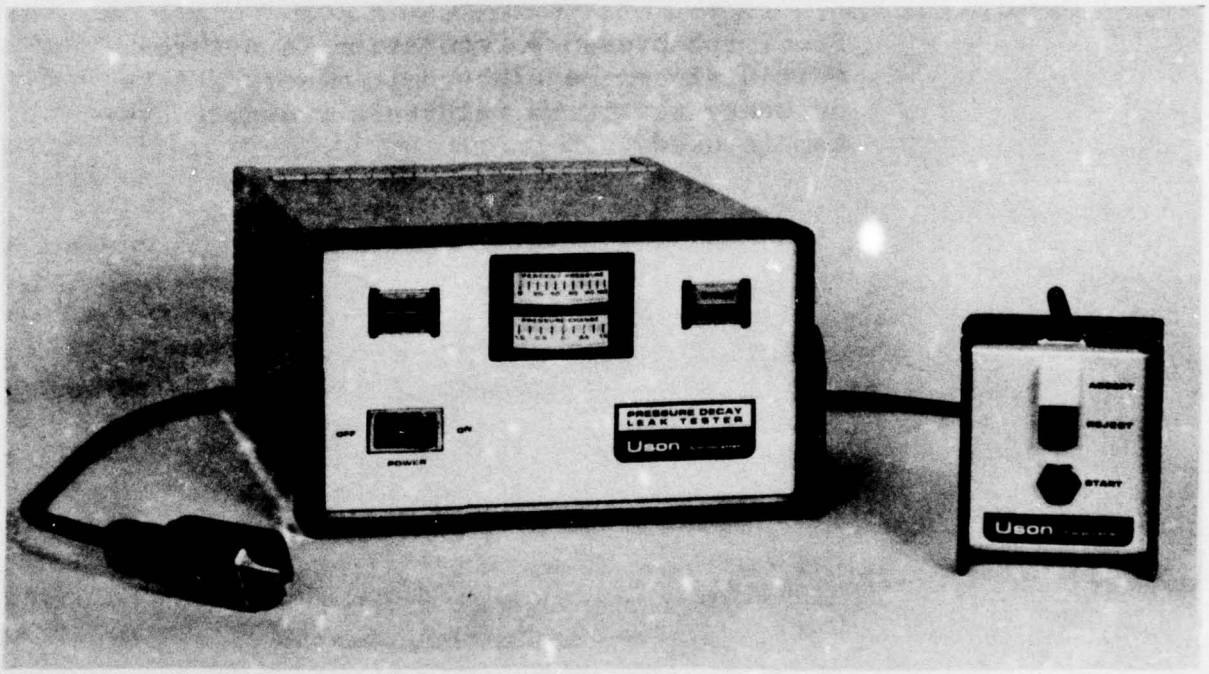


Figure 20-32. Uson's Pressure Decay Leak Tester.

Description: The Uson Pressure Decay Leak Tester automatically detects a 0.05% pressure change, has an automatic cycle which is programmable and operates over a pressure range from -15 to + 3000 psig. Pressure sensitivity range, delay time, test time, and set point are easily programmed on automatic units at hidden panel at top rear of electronics unit. Pressure sensitivity range is adjusted on front panel of manual units.

Its operating principle is as follows:

The test item is charged with air or other gas to the test pressure through a manual or solenoid valve. The valve is closed, and an electronic pressure transducer continuously measures the trapped pressure in the test item. The initial pressure is stored in an electronic memory. Any pressure loss from the initial pressure is determined after a time period to determine possible leakage.

Precision pressure regulation is not required since the electronic memory resets on every test. No reference pressure system is used.

Name:	Inward and Outward Leak Test Stand
Manufacturer:	ARO Corporation, One Aro Center, Bryon, Ohio 43506/(419)636-4242
Model:	OT-170-1 Figure No.: 20-33
Size:	36 in L x 46 in W x 56 in H Weight: 295 lbs.
Power Requirements:	25 in vacuum, H_2O at 10 CFM; Oxygen/ Nitrogen at 2000 psi.
National Stock No.:	4920-00-673-5923

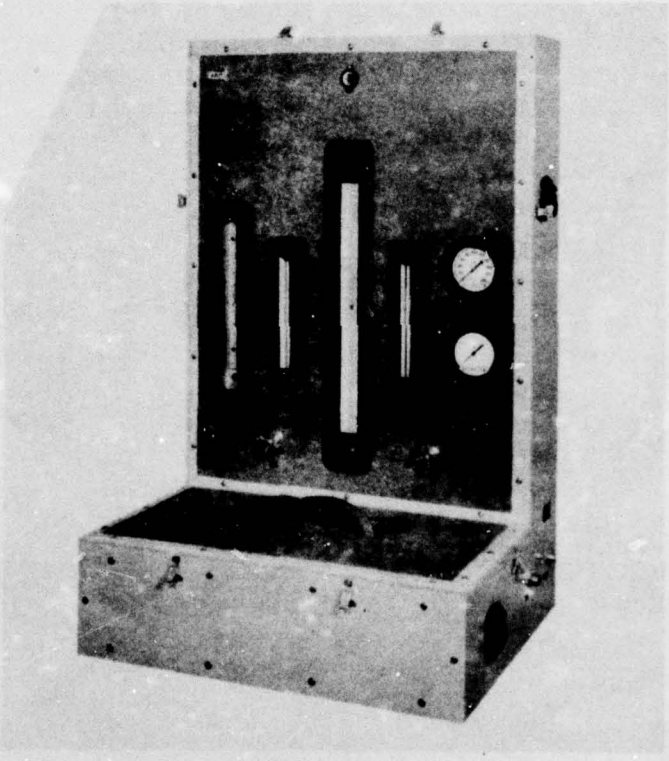


Figure 20-33. ARO's Oxygen Leak Test Stand.

Description: The Model OT-170-1 Inward and Outward Leak Test Stand is designed to test demand oxygen regulators on a work bench. It consists of an inlet pressure gauge (0-2000 psi), an operating pressure gauge (0-200 psi), two valves, two flowmeters, two manometers, a gauge protector and a regulator. The flowmeters are rated at 0.02 - 0.35 LPM

(20 - 350 cc/min) and the manometers at 0 -15 in H_2O(U Tube) and 0 -24 in. H_2O (Single Tube).

20-2.6 DYNAMOMETERS-TORQUE/SPEED/POWER MEASUREMENT

Name:	Series 061 Dynamometer
Manufacturer:	Kahn Industries, Inc., 885 Wells Road, Wethersfield, Conn. 06109/(203)529-8643
Model:	061-124 Figure No.: 20-34
Size:	24.5 in diam. x 11 in L Weight: 305 lbs.
Power Requirements:	Water flow: 4 gPH/HP, 50 psig
National Stock No.:	

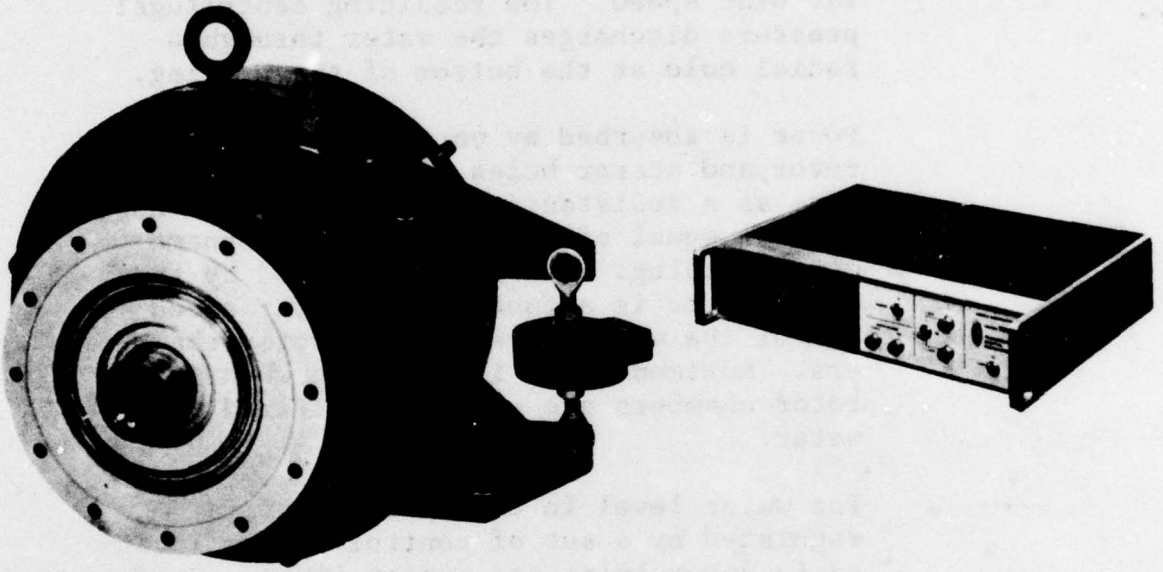


Figure 20-34. Kahn's 061 Dynamometer.

Description: The series 061 dynamometer is used as a power absorber for testing helicopter engines. It comes in five models providing a capacity up to 3500 HP and a speed range up to 19,000 RPM. Model 061-124 is rated at 1750 HP, 6000 RPM and 2000 ft lbs torque. The readout system employed is a universal strain gauge load cell suspended between torque arms. A solid state analog torque indicator is standard; a digital indicator unit is optional.

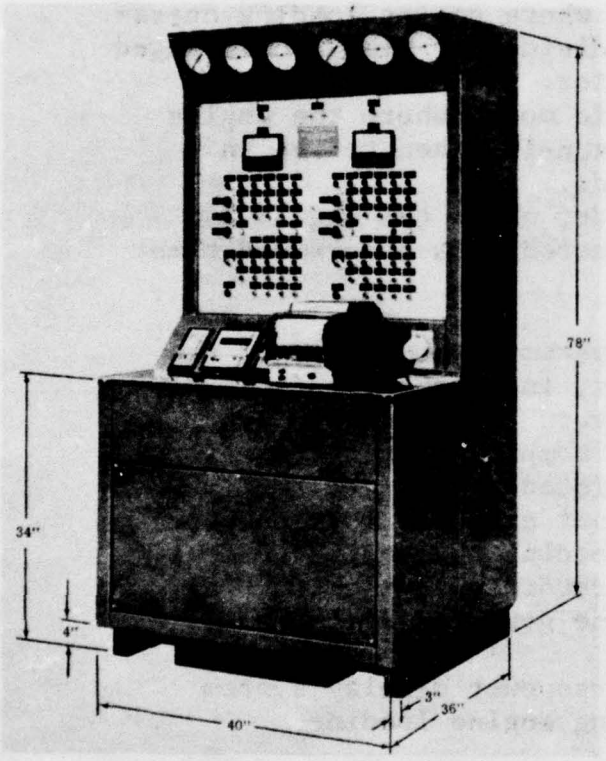
A series 061 dynamometer consists of one or two perforated discs enclosed in a housing and rotating between similar sets of perforated stators. Cold water enters each rotor chamber at the center. The water is accelerated by the rotating disc and thrown outwards by centrifugal action. From the outer diameter of the rotor chamber inwards, the water forms an annulus which rotates at approximately half of the angular disc speed. The resulting centrifugal pressure discharges the water through a radial hole at the bottom of the housing.

Power is absorbed by vortices created in rotor and stator holes. The resulting drag acts as a resistance to rotation and tends, with an equal effort, to turn the dynamometer housing. The power absorbed by the dynamometer is a function of rotor speed and of the water level in the rotor chambers. Maximum power is absorbed when the rotor chambers are completely filled with water.

The water level in the dynamometer is regulated by a set of control valves located in water inlet and outlet lines. Opening of the inlet control valve or closing of the outlet control valve causes the water level to increase. Closing of the inlet control valve and opening of the outlet control valve causes the water level to decrease.

The power absorbed in the dynamometer is converted into heat. In order to remove the heat, a continuous flow of water through the dynamometer is required. As a rule, a flow of four gallons per hour per horsepower (4 GPH/HP) is sufficient, assuming water temperature increase of 76F across the dynamometer.

Name: 30 HP, Two Station Dynamometer Test Stand
Manufacturer: Cox Instrument Division, Lynch Corporation, 15300 Fullerton Ave., Detroit, Michigan 48227/(313)838-5780
Model: 83960D Figure No.: 20-35
Size: 43 in L x 36 in W x 84 in H Weight: 1200 lbs
Power Requirements: 220/440 VAC, 60 Hz, 3 Phase; 3.5 Gal/HP water flow
National Stock No.: 4940-00-044-7184



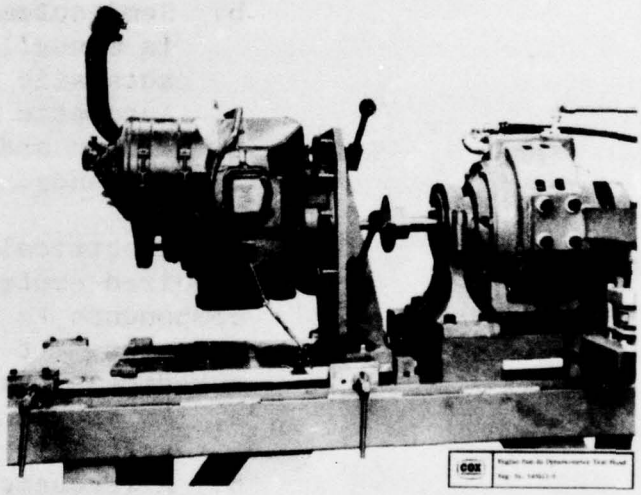


Figure 20-35. Cox Instrument's Engine Run-In Dynamometer Test Stand.

Description: The Cox Instrument Model 83960D Dynamometer Test Stand is used to test high performance gasoline engines with 1.5, 3, and 6 HP ratings. It consists of a single two-station control console and two absorber engine run-up test benches. The dynamometer used is an eddy current absorber system requiring a hydronic system to circulate water

through it to remove heat produced during test operations.

The Engine Run-In and Governor Test Stand Assembly is comprised of the electronic packages, electrical controls, and hydronic cooling system required for testing, displaying, and recording the required engine operational parameters. Testing may be accomplished in any of three modes, as follows:

a. Manual mode, where engine loading operations are individually timed and changed by the operator.
b. Semi-automatic mode, where the engine is manually run-in, then tested in automatic mode.
c. Automatic mode, where the engine is run-in and tested in a programmed time sequence.

The electrical system is comprised of the required controls, indicators, and timing components to govern the selected test sequence. It is comprised of three major subsystems, as listed below:

a. An eddy current absorber (dynamometer) system for loading the engine on test.
b. A frequency recording system for recording engine governor performance during test.
c. A digital horsepower display system for indicating engine loading.

Name: ECO-TRAC Road Test Simulator
Manufacturer: Allen Testproducts Division, the Allen Group, Inc., 2101 N. Pitcher Street, Kalamazoo, Michigan 49007/(616)345-8531
Model: 24-200 Figure No.: 20-36
Size: 10.75 in H x 87 in W x 33 in D Weight: 1010 lbs.
Power Requirements: 115 VAC, 60 Hz; Air Source - 120 psi
National Stock No.:

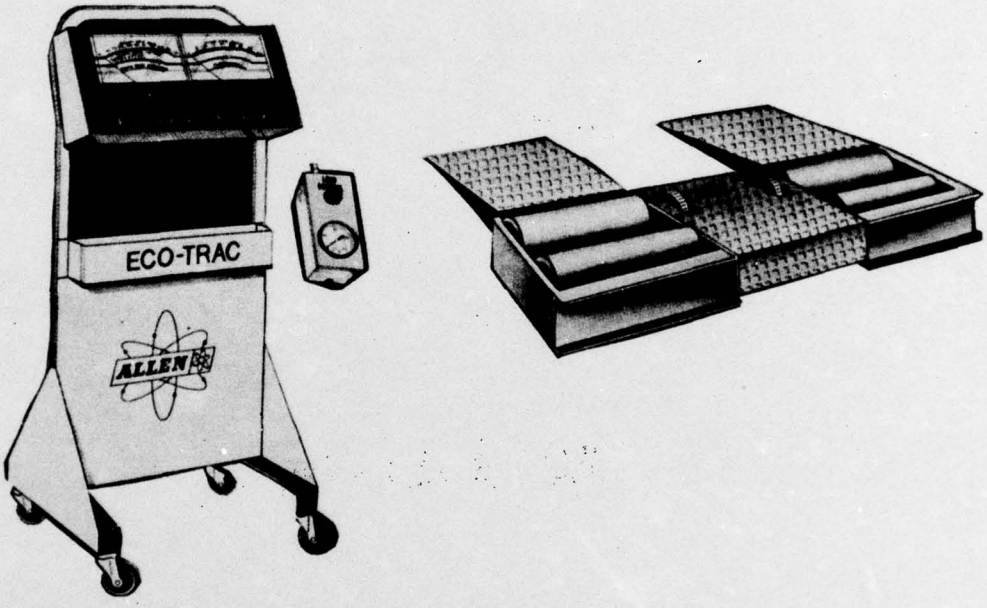


Figure 20-36. Allen Testproducts ECO-TRAC Simulator.

Description: The ECO-TRAC Road Test Simulator is designed to supplement engine analyzers with road simulation data. It provides engine rating/performance, transmission/drive train condition, speedometer accuracy and miles per gallon at a set road speed. The simulator consists of a roller and brake assembly, approach ramps(2), drive-over plates(2), wheel chocks(2), fuel transducer, two meter mobile cart with 8" meters,

hand-held load control unit with 2" pressure gauge, hand-held miles-per-gallon push-button unit, and leads, hoses, accessories, etc.

Name: Challenger C-720 Chassis Dynamometer
Manufacturer: Clayton Manufacturing Company, 4213 North Temple City Blvd., P. O. Box 550, El Monte, Ca. 91734/(213)443-9381
Model: C-720 Figure No.: 20-37
Size: 120 in L x 36 in W x 8.75 in H Weight:
Power Requirements: 115 VAC, 60 Hz, Single Phase; Air Pressure - 75 psig; Water Supply - 30 psi, 18 GPM
National Stock No.:

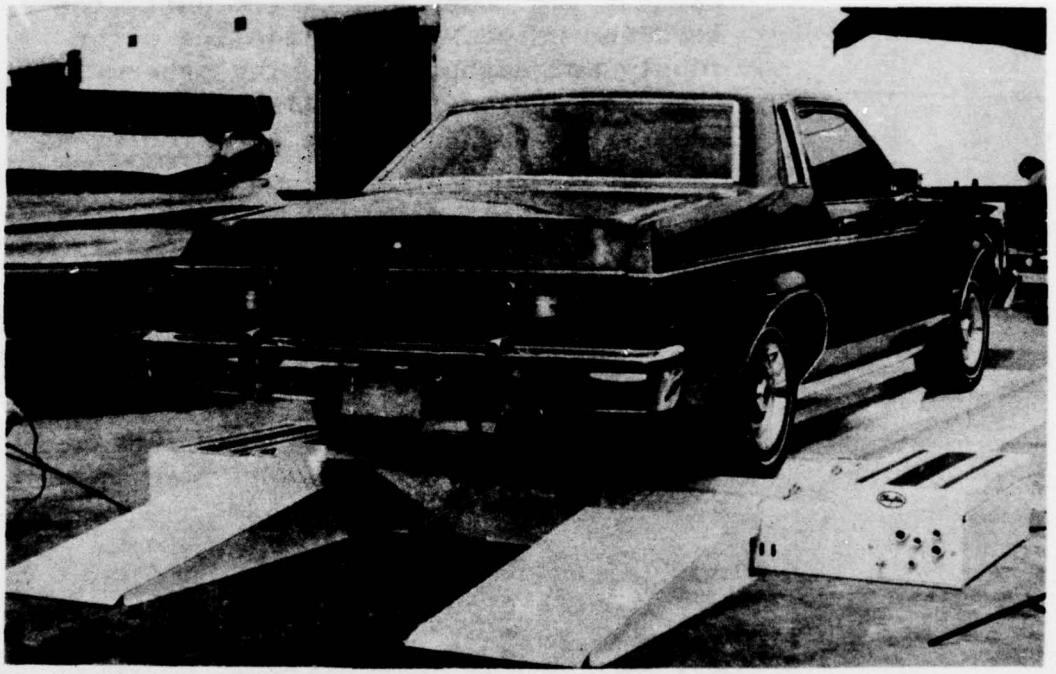


Figure 20-37. Clayton Model 720 Chassis Dynamometer.

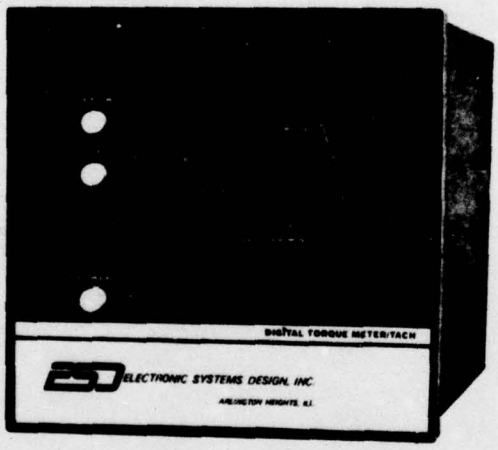
Description: The Clayton Chassis Dynamometer is capable of absorbing 200 horsepower at speeds from 50 to 120 miles per hour. Direct readout is provided of miles per hour and road horsepower. Its power absorption unit utilizes rotor and stator vanes to accelerate and decelerate fluid to absorb vehicle power.

The Model C-720 Chassis Dynamometer consists of the following major components:

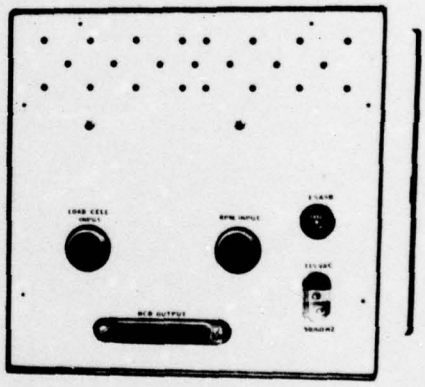
a. A unitized steel frame designed to accommodate all available options for factory or field installation.
b. A pair of sound-dampened rolls provide a cradle in the form of a "treadmill" to support the vehicle drive wheels and furnish a means for transmitting speed and power readings of the vehicle being tested to read-out instructions.
c. A power absorption unit section containing the power absorption unit, the load and unload valves, cooling water supply and disposal plumbing, thermostatic water control valve, tachometer generator, torque bridge and electrical component junction box.
d. An air-actuated platform lift to lower or raise the vehicle on or off the rolls and actuate the roll brakes for vehicle removal when the lift is raised.
e. A remote control pendant which is a hand control, used to operate the load and unload valves from the vehicle. Push-button switches mounted in the pendant, when depressed, energize the load or unload valves.

Optional accessories include a closed load system, inertia flywheel system, guide control, remote control constant speed control system, speedometer test feature, treated rolls and ramps, etc. for top floor installation.

Name: ESD Digital Torque Meter/Tach
Manufacturer: Electronic Systems Design, Inc., 317 W, University Drive, Arlington Heights, Ill. 60004/(312)398-0550
Model: 7600 Figure No.: 20-38
Size: 2 in H x 8 in W x 14.5 in D Weight: 19.5 lbs.
Power Requirements: 115 VAC, 60 Hz
National Stock No.:



Front Panel



Rear Panel

Figure 20-38. ESD's Digital Torque Meter/Tach.

Description: ESD's Model 7600 electronically displays torque and RPM based on inputs of a strain gauge load cell (2 mv/volt minimum), lever arm length (up to 100 ins.) and 60 pulse per rev. train (0.2 p/p min. level). It updates its display once every second. Options include a load cell for torque input and an electromagnetic pick-up for detecting RPM pulses from a 60 tooth gear. Features of the unit are:

- Display both torque and RPM simultaneously
- Load cell input eliminates beam scales.. load cell supply contained in meter.
- Built-in calibration and test circuits.
- Gas discharge display provides excellent legibility under high ambient light conditions.
- Optional digital outputs for data logging and processing (including closed loop control).

Name: Dynapul System
Manufacturer: Grecian and Associates, 11404 Sorrento Road, San Diego, California 92121/(714)453-1856
Model: 12P8-120 Computer Figure No.: 20-39
Size: 12 in W x 4.5 in H x 12 in D Weight: 5 lbs.
Power Requirements: 120 VAC, 60 Hz or 12 VDC
National Stock No.:

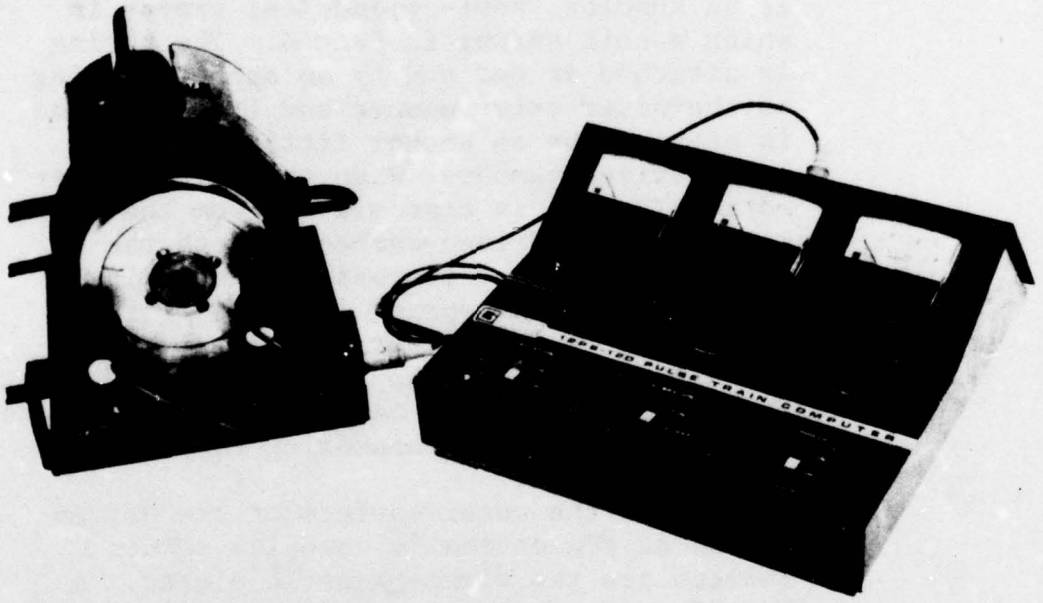


Figure 20-39. Grecian and Associates' Dynapul System.

Description: The Dynapul System accurately displays speed, torque and power being transmitted under load conditions. The system uses two reluctance pickups arranged axially with respect to the axis of rotation of the transducer. The transducer is embodied in a V-belt pully wherein the drive member is adapted for mounting on the drive shaft on an electric motor. The drive member is in the form of an annular rim having a V-shaped groove in its periphery to receive the V-belt. The driven member includes a

circular disc which is mounted on a hub having a central bore to receive the drive shaft of the motor. The bore is slotted to receive a key for keying the transducer to the motor shaft. Circular end plates are attached to opposite sides of the disc and these plates confine the rim between them while allowing relative rotation of the rim with respect to the disc.

Formed in the outer periphery of the disc is an annular, semi-cylindrical groove in which a coil spring is seated. The spring is attached at one end by an anchor fitting to the outer drive member and its other end is attached by an anchor fitting to the inner driven member. When the drive member rotates torque is transmitted from the drive member to the driven member through the spring. As torque increases, the spring stretches and the spring is capable of stretching to the extent of allowing the drive member to turn approximately 170° with respect to the driven member which represents the limits of torque-measuring capability.

Mounted on the outer surface of the driven member at diametrically opposite points thereon are two ferro-magnetic cleats. A second pair of cleats are fixed to the outer face of the outer plate at diametrically opposite points thereon, the cleats being spaced 90° from inner cleats when transducer is at rest.

Mounted on a base is a bracket which holds two reluctance pickups. One pickup is positioned to be in the path of the inner cleats as they follow their circular path, while the other pickup is located in the path of the outer cleats as they travel their circular path. The pickups are mounted on a curbed holder which is adjustable and allows angular adjustments of the pickups one to the other. Wires lead from the pickups to the pulse train computer.

As the transducer rotates on the motor shaft the pickups send out voltage pulses each time that one of the cleats passes the pole piece of its respective pickup. The speed range of the Dynapul System is from 15 RPM to 12,000 RPM.

Name: Drive Line Dynamometer
Manufacturer: Grecian and Associates, 11404 Sorrento Road, San Diego, California 92121/(714)453-1856
Model: XP453 Figure No.: 20-40
Size: 5.75 in L, 3.25 in Diam. Weight:
Power Requirements: 12 VDC
National Stock No.:

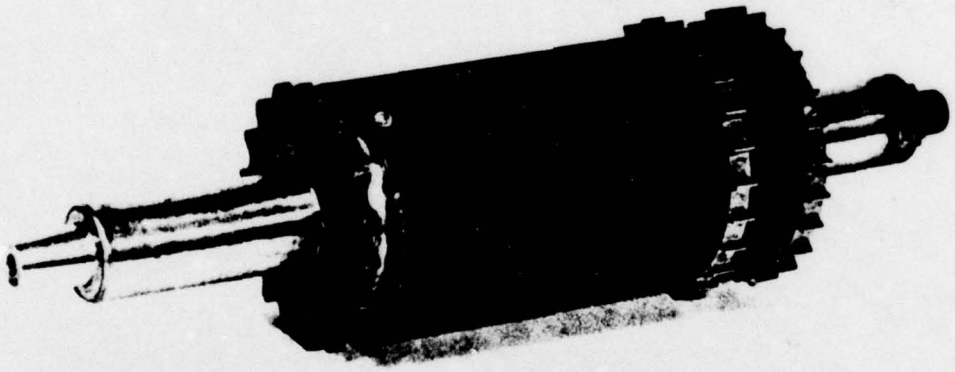


Figure 20-40. Grecian and Associates' Transducer for Drive Line Dynamometer.

Description: The Drive Line Dynamometer was developed for automobile racing to scientifically monitor engine performance. In this application the transducer becomes a permanent part of the vehicle. The system delivers readings of horsepower, RPM and torque. It consists of the transducer and a cockpit computer which displays the three values. Installation is as follows:

First the drive line is disconnected and 5-3/4 inches removed from it. Although this section may be removed wherever it is convenient, the usual

place is at the front end, where the yolk half attaches to the drive line, and connects to the U-joint just behind the transmission. After the 5-1/4 inch section is removed, the yolk half connected to the torque tube is rewelded, the shroud ring containing the pulse pickups for the transducer is clamped to the end of the transmission tailpiece, and the transducer itself placed inside the ring. At this point the yolk half of the transducer is connected to the yolk half of the torque tube using the standard U-joint cross just as it was in place before installation. No driveshaft rebalancing is usually necessary since all transducers are dynamically balanced to 1/10 oz in. Then the three wires from the transducer are wired to the cockpit of the automobile in any convenient manner. The computer itself may be installed wherever the customer desires although the recommended position is under the dashboard. It uses a standard automatove 12-volt DC power supply and gives readings as soon as the drive line begins to turn.

Name: System 6 Hydraulic Motor Output and Efficiency Instrument.

Manufacturer: S. Himmelstein & Co., 2500 Estes Avenue, Elk Grove Village, Illinois 60007/(312) 439-8181

Model: System 6 Figure No.: 20-41

Size: 3.5 in. H x 17 in. W x 17.6 in. D

Power Requirements: 105-130 VAC, 50-400 Hz., 75 VA

National Stock No.:

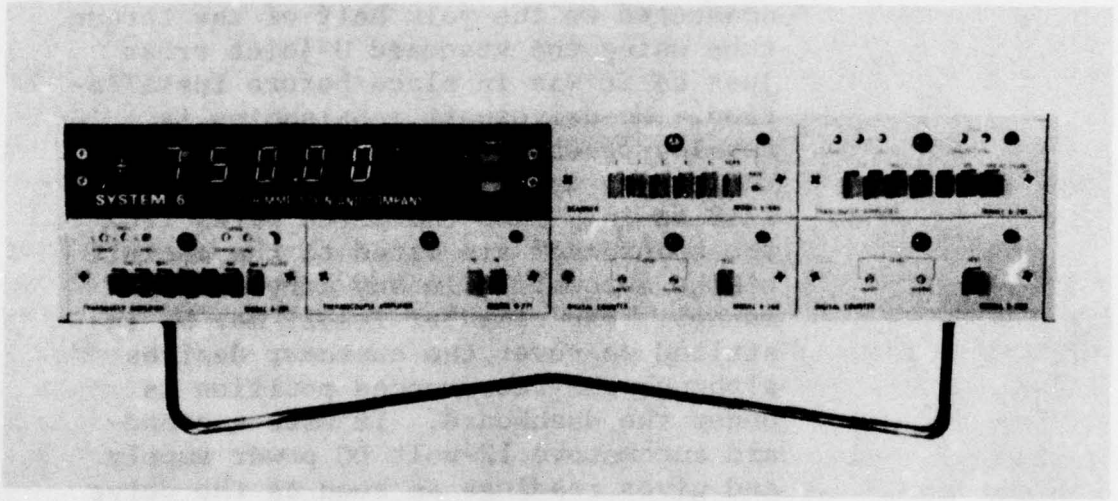


Figure 20-41. S. Himmelstein & Co.'s System 6 Monitoring Instrument.

Description: System 6 is a modular transducer oriented instrument for the measurement and/or control of physical data and processes. All data, whether originating as an input or derived within the system, can be automatically scanned and displayed on the integral Digital Display with engineering unit scaling and identifying, illuminated legend. Input and/or processed data can be combined with each other and/or with fixed constants to derive computed results. Also integral to the unit is a scanner and an A/D converter.

The Scanner has two modes of operation; MANUAL and SCAN. In the MANUAL mode, the operator selects a channel for display by depressing a latching, front panel pushbutton. In this mode, critical parameters can be continuously monitored, set-up operations performed, etc. Alternately, the operator can select the SCAN mode. In this mode, each channel is scanned automatically, without operator intervention. By way of illustration, a SYSTEM 6 may be organized to read TORQUE, SPEED and computed POWER. When the operator engages the SCAN pushbutton, TORQUE, SPEED and POWER will be displayed, in sequence, on a continuous basis. Scan rate is adjustable from the front panel. Pushbutton controls allow the operator to SKIP any channel or combination of channels from the SCAN sequence.

Analog data signals are converted to digital form by the A/D Converter. Conversion allows subsequent display in digital form, computation and/or classification, storage, and/or printing by peripheral digital devices. Three levels of accuracy are available. Thus, each SYSTEM 6 configuration can be delivered with the precision and resolution dictated by the application.

Optional modules for the SYSTEM 6 consist of transducer amplifiers, digital counter, thermocouple amplifier, scanners, digital multiplier/scanner, digital tare/scanner, dual digital limits, dual analog limits and track/hold/peak module.

Inputs to the system generally consist of analog and digital transducers conveying information such as weight, force, pressure, torque, displacement, liquid level, flow, acceleration, speed, time, angular position, switch closures, etc. Typical applications are: blower torque/speed testing, electric motor data acquisition system,

engine test cell instrumentation system, transmission efficiency measurement, and hydraulic motor out-put and efficiency measurement.

20-2.7 ENGINE/IGNITION ANALYZERS

Name:	Allen-tronic Diagnostic System II
Manufacturer:	Allen Testproducts Division, The Allen Group, Inc., 2101 North Pitcher Street, Kalamazoo, Michigan 49007/ (616) 345-8531
Model:	18-010 Figure No.: 20-42
Size:	67 in.H x 22 in.D x 48 in.W Weight: 340 lbs
Power Requirements:	115 VAC, 60 Hz.
National Stock No.:	--

Figure 20-42. Allen's 17 Inch Solid-State Engine Analyzer

Description: The Allen-tronic Diagnostic System II is capable of testing 4,6, and 8 cylinder plus rotary engines. It is designed with pushbutton function

control for ease of operation and contains a large 17-inch scope for display. Its capability includes:

TEST SELECTION: Indicator lights work when each test button is depressed as below. RPM: 0 to 1500; 0 to 10,000 RPM - Automatic ranging in all test modes.

CRANK/KILL: Voltmeter: 0-20 volts, 0-40 volts. Automatic scale and polarity selected. Ammeter: 50 to 0 to 500 amps. Carbon Pile Battery Load Test: -500 amp capacity. Point Resistance: Dynamic reading when button depressed cranking engine.

CHARGE: Voltmeter: 0 to 20, 0 to 40 volts, Ammeter: 10 to 0 to 90 amps. Scope Pattern: Automatic alternator test 0-4V isolated.

PRIMARY: Scope - Parade, superimposed, pattern stacked or raster. Dwell - Automatic: 0 to 90°.

TIME: Timing Light, advance meter 0-90°.

SECONDARY 20 KV: Scope - Parade, superimposed, pattern stacked or raster. 5 millisecond sweep feature. Cylinder select.

SECONDARY 40 KV: Scope - All scope patterns and cylinder select and power balance test.

NOTE: Special pattern shift for point open viewing on cylinder selector.

VACUUM/PRESSURE:

0-25 inches vacuum	0-12 PSI
0-600 MM/Hg	0-0.8 Kg Cm

OHMMETER: 0-500, x 1, x 10, x 100, x 1000 ohms

Name: Beckman Engine Scope Tester

Manufacturer: Beckman Instruments, Inc., Process Instruments Division, 2500 Harbor Blvd, Fullerton, California 92634/(714) 871-4848

Model: 595 **Figure No.:** 20-43

Size: 10.5 in. H x 21.5in. W x 15in.D

Weight: 38 lbs (w/o cart)

Power Requirements: 115 VAC, 60 Hz

National Stock No.:

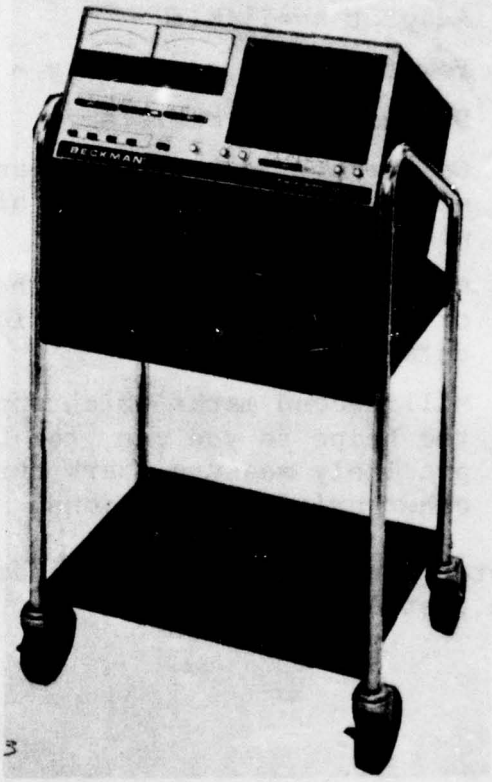


Figure 20-43. Beckman's Engine Scope Tester

Description: The Model 595 Engine Scope Tester features an 11 inch scope with expansion capability as well as parade, superimposed, and stocked plus cylinder of interest from parade and time marks. Two meters are provided with tachometer ranges (400-1200

RPM and 0-6000 RPM), dwell range (0-90 degrees), voltmeter ranges (0-4 VDC, 0-40 VDC) advance and retard range (-45 to +45 degrees), dynamic point resistance (0-0.5 volts). Additional features are:

- Full-screen display of any cylinder from parade, while the other cylinders remain in view in parade pattern.
- Both advance and retard timing capability with timing light.
- Universal ignition capability - standard breaker, capacitive discharge, magnetic, and transistorized. High Energy Ignition Adapter available.
- Power balance capability - even with HEI.
- Dynamic point resistance.
- Calibrated four-times expansion which gives you the equivalent of a 30-inch wide screen.
- Additional expansion to the equivalent of a 60-inch wide screen for even more detailed analysis.
- Millisecond marks which appear right in the scope so you can, for the first time, precisely measure spark duration and other critical functions.

Rotary and 4 through 8 cylinder engines may be tested by the Model 595.

Name: Clayton Engine Analyzer
Manufacturer: Clayton Manufacturing Company, 4213 North Temple City Blvd., P.O. Box 550, El Monte, California 91734/(213) 443-9381
Model: CSS/5101 Figure No.: 20-43
Size: 27in. W x 15in.H x 18in.D Weight: 80 lbs
Power Requirements: 115 VAC, 50/60 Hz
National Stock No.:

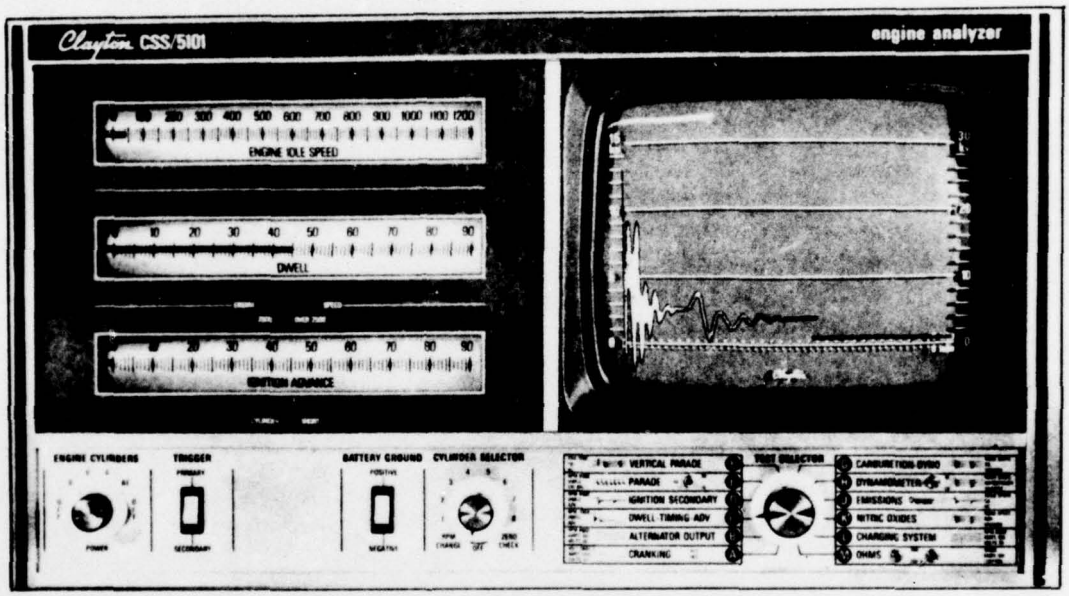


Figure 20-44. Clayton's CCS/5101 Engine Analyzer.

Description: Clayton's Model CSS/5101 Engine Analyzer tests rotary and 4 through 8 cylinder engines. It has a 12 inch scope and 3 display meters. The display meters feature a 9 inch horizontal scale with 6 scales each contained on a drum. Twelve types of tests are selectable by a rotary switch including cranking, alternator output, dwell-timing-advance, ignition secondary, parade, vertical parade, carburetion-dyno, dynamometer, emissions, nitric oxides, charging system, and ohms. The engine analyzer is designed to work in conjunction with Clayton's Chassis Dynamometer and Nitric Oxide Sampler.

The horizontal scales (rotometers) change automatically with the selector switch. These meters have the following scales: engine idle speed, percent carbon monoxide, hydrocarbons, engine speed, dwell, engine speed change, ignition advance, amperes voltage drop, road speed, vacuum, road horsepower, nitric oxides, and ohmmeter.

Name: Marquette Engine Analyzer
Manufacturer: Marquette, The Performance/Safety Test Division, Automotive Service Systems Group, St. Paul, Minnesota 55112/(612) 484-8501
Model: 40-276 **Figure No.:** 20-45
Size: 16 in. scope **Weight:** 273 lbs
Power Requirements: 120 VAC, 60 Hz
National Stock No.: --

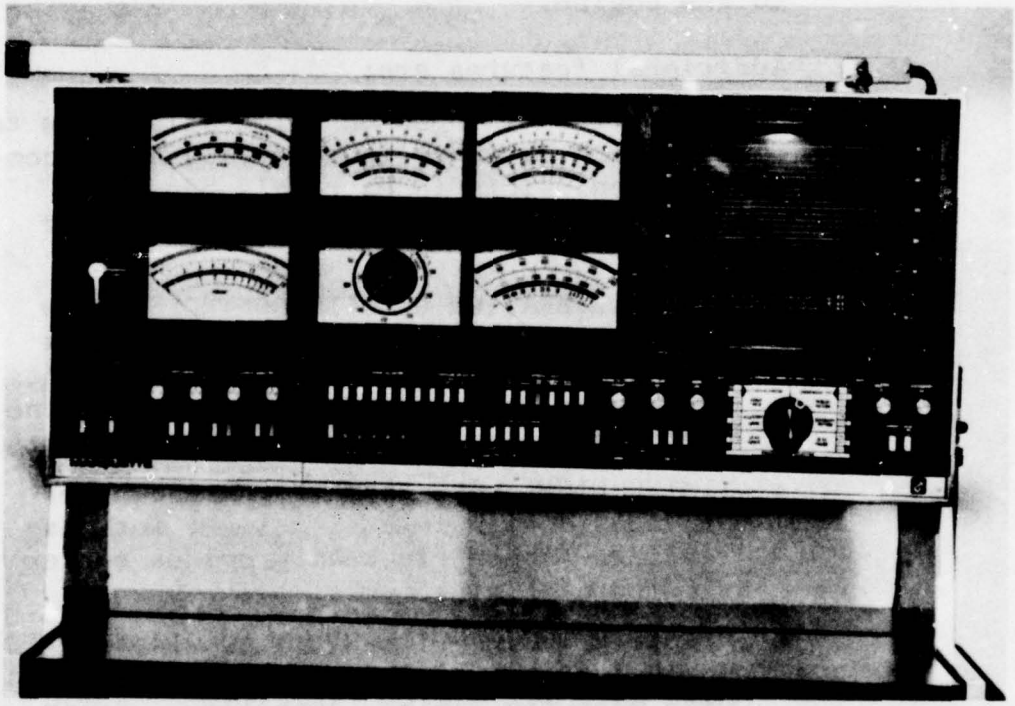


Figure 20-45. Marquette's Model 40-276 Engine Analyzer

Description: The Marquette Model 40-276 Engine Analyzer provides programmed test selection via push-button and rotary switch control. It is designed for dynamic testing of compression, ignition, carburetion and cranking/charging systems of spark ignition engines. In addition, it is equipped for testing electronic fuel injection systems. It tests two and four cycle engines equipped with either the

conventional breakerpoint ignition system or with any electronic ignition system now on the market. The same hook-up is used to test 6, 12 and 24 volt electrical systems, both positive and negative ground.

The operating controls are designed to test all systems and components with a minimum of lead changing and in the same sequence every time, thus saving time and assuring complete testing. In addition the test leads are of the induction type to speed analyzer hook-up to the engine.

Additional features are:

- PUSHBUTTON CYLINDER SELECTOR allows you to test each cylinder individually or in combination. This is extremely handy for testing cylinder balance and carburetor balance.
- SELF-CALIBRATION CIRCUIT CONTROLS allow you to calibrate scope KV, dwell, spark advance, voltmeter, expanded tach, points resistance and raster spacing without the need for separate calibration instruments.
- TIMING LIGHT with spark advance control provides a high intensity light for easy reading. Eccentric beam provides easier viewing of timing marks.
- MAGNETIC TIMING PICK-UP is provided to check ignition timing on engines equipped with magnetic timing capability. Separate magnetic timing scale is also provided.
- OSCILLOSCOPE is easy to read, has large 16" screen that provides sharp, bright patterns. Displays voltage waveforms of primary superimposed, secondary superimposed, all cylinders parade, alternator conditions, electronic fuel injection, plus calibration patterns for checking accuracy and re-calibrating.
- AUTOMATIC RANGING selects the desired tachometer scales between 1200 and 3600 RPM. No need to push buttons.

The Model 40-276's specifications includes:

Engine Speed	0-1200, 0-3600, 0-12,000 RPM
Voltage	0-2, 0-20, 0-40 Volts
Points Resistance	Normal/High measured with engine running
Spark Advance	0-90°, 0-180°
Accessory Pick-up	A separate set of test leads 15 feet long for testing fuel injection systems and additional transducer pick-up signals developed in the future.
Point Dwell	0-90°, 0-180°
Amperes	50-0-50, 100-0-100, 500-0-500 Amps
Ohms	3 ranges - 0-500, 0-5000, 0-500,000 ohms
Hydrocarbon	0-500, 0-2000 P.P.M.
Carbon Monoxide	0-2.5, 0-10 percent
Cylinder output	150-0-150, calibrated in RPM at 1000 RPM engine speed
Secondary Trigger	When primary triggering is not accessible
Vacuum	0-30 inches, 0-700 mm. Hg.
Pressure	0-14 pounds, 0-1 bar (atmosphere)
Test Leads	9 feet long with break-away at overhead boom
Ammeter Pick-up	Clamp-on with 20 ft lead
Timing Light	15 ft. lead, incorporates advance control
Ohmmeter Lead	15 ft., with Mueller clip and test probe
Vacuum/Pressure	Neoprene tubing with bulk-head fitting
Battery Load	Provided to test charging system.

Name:	Magneto Ignition Analyzer
Manufacturer:	Merc-o-tronic Instruments Corporation, 215 Branch Street, Almont, Michigan 48003/(313) 798-8555
Model:	98A Figure No.: 20-46
Size:	9 in.W x 8 in.D x 9 in. H Weight: 19 lbs.
Power Requirements:	115 VAC, 60 Hz; 7.5 or 12 VDC Battery
National Stock No.:	4910-00-451-7949

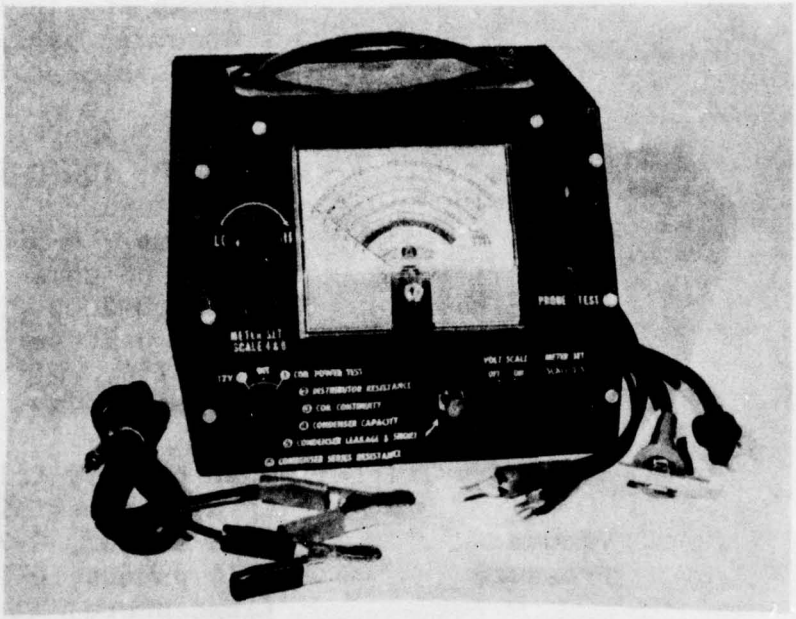


Figure 20-46. Merc-o-tronic Instruments' Ignition Analyzer

Description: Merc-o-tronic's Model 98A is a simple transistorized instrument having a single meter readout and designed to test outboard motors. It has the following test capability: high and low speed coil test, coil continuity test, coil primary test, insulation test, distributor resistance test, distributor caps, starter solenoid test, diode test, condenser capacity test, condenser series resistance test, motor timing, spring tension test and high/low ohm scales. Available is a capacitor discharge adaptor to check coils used in conjunction with solid state ignition systems.

Name:	Magneto Ignition Test Stand
Manufacturer:	Sun Electric Corporation, 3011 East Route 176, Crystal Lake, Illinois 60014/(815) 459-7700
Model:	MIT Figure No.: 20-47
Size:	28in. L x 30in. W x 26in. H Weight: 400lbs.
Power Requirements:	220/440 VAC, 3 Phase, 60 Hz.
National Stock No.:	4910-00-912-3960

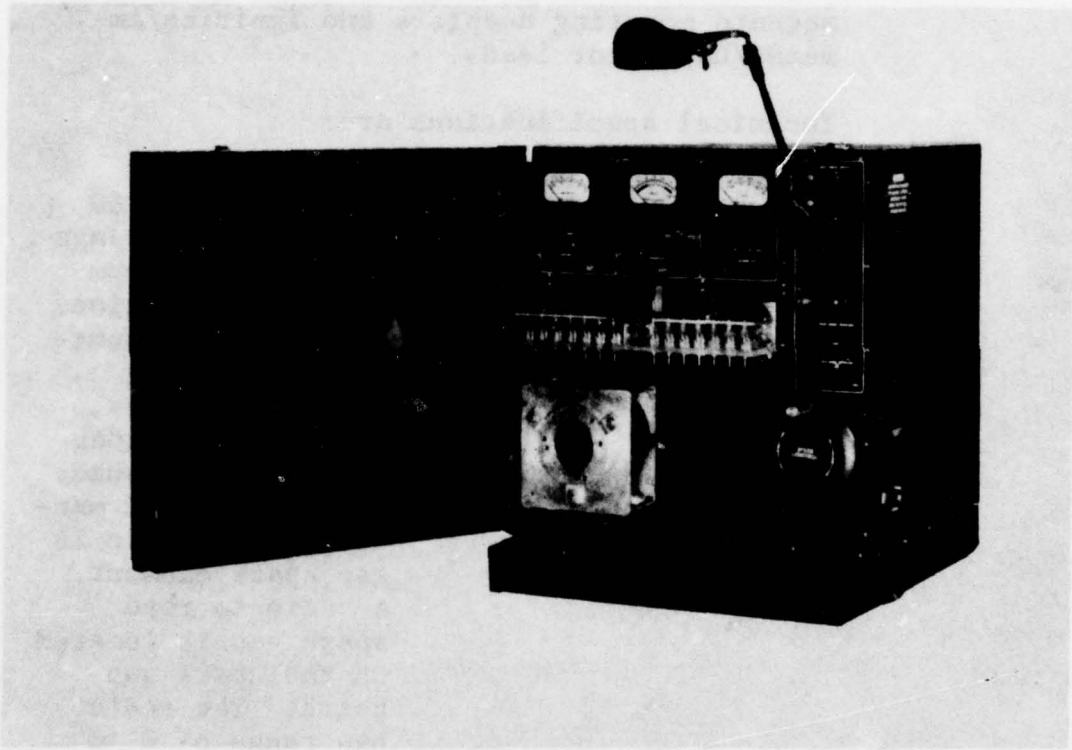


Figure 20-47. Sun Electric's Magneto Ignition Test Stand

Description: The Sun Electric Corporation Magneto Ignition Test Stand, Model MIT is a self-contained unit, requiring only electrical power for operation. The tester is designed for bench or table top operation. Provisions for mounting the tester to a bench or table are provided.

The tester is designed to functionally test a wide variety of ignition magnetos over a selectable speed range of 30 to 4200 rpm. Test facilities are also provided to check the lag angle, lug angle, impulse cutout speed, and coming-in speed. Additional capabilities include testing magneto ignition capacitors; including feed-through types for capacitance, series resistance, ground and leakage resistance.

Accessories include magneto drive adapters, magneto mounting adapters and Ignition/Ammeter/Capacitor leads.

Technical specifications are:

Variable Speed Drive	3/4 Hp, 220/440 volt, 3 phase, 60 cycle. Speed range of 30 to 4200 rpm. CW or CCW rotation.
Magneto Drive and Mount	Provides for mounting and driving various magnetos. All necessary adapters are furnished.
Spark Gap Board	A three element manually adjustable 14 gap spark element. A scale to read spark gap is located on the spark gap board. The scale has range of 0 to 15 MM.
Capacitor Tester	Tests capacitors from 0.1 to 1.6 mfd, 3.5 megohms at 500 volts DC.
Spark Advance or Retard Indicator	Adjustable, 0-260 degree scale provides for measurement of spark, advance, retard firing angle, lag angle and lug angle.

Tachometer	Dual range, 0 to 500 rpm and 0 to 5000 rpm.
Ammeter (AC)	Dual range 0 to 2.5 amps and 0 to 5.0 amps.

Name: Engine Performance Tester
Manufacturer: Sun Electric Corporation, 3011 East Route 176
Crystal Lake, Illinois 60014/(815)459-7700

Model: EET-940 Figure No. 20-48
Size: 46in. L x 30in. D x 77in. H **Weight:** 550 lbs.
Power Requirements: 120 VAC, 50/60 Hz.
National Stock No.: --

Figure 20-48. Sun Electric's Model 940 Engine Performance Tester.

Description: The Model EET-940 Engine Performance Tester consists of a volt leakage unit, 23-inch scope, tachometer dwell unit, fuel pump tester, timing advance unit and a test harness boom. It tests two- and four-cycle and rotary engines in motor vehicles, aircraft ground support equipment, stationary and marine power plants. Applies to conventional

or transistor ignition systems and many magneto systems. Uses the same hook-up for testing 6, 12, 24 and 32 volt electrical systems, positive or negative ground, regardless of number of engine cylinders. Comes complete with an illustrated instruction manual and the following accessories: solenoid starter switch, high-tension pliers, resistance-test contactor, vacuum fitting set, cylinder leakage hoses, whistle and test lamp and fuel pump tester.

The sturdy steel headframe contains the following:

A Voltmeter with scales reading from 0 to 4, 0 to 16, and 0 to 40 volts.

An Ohmmeter with scales reading from 0 to 100, 0 to 1000, 0 to 10,000 and 0 to 100,000 ohms.

A Condenser Tester capable of testing series resistance, leakage and capacity of 0.1 to 1.0 mfd condensers, on or off the vehicle.

A Cylinder Leakage Tester to pinpoint compression leaks.

An "Auto-Ranging" Tachometer, triggered by spark plug firing signals, with scales of 400 to 1000, 0 to 5000, 0 to 10,000 RPM. It switches automatically between the 1000 and 5000 RPM ranges.

A pushbutton Electronic Cylinder Balance Test which allows the operator to "kill" any combination of cylinders simultaneously for measurement of power and carburetor balance at any RPM.

A Dwell Meter with scales for testing 4, 6, or 8 cylinder engines and a Percent-of-Dwell scale for use with engines other than the standard 4, 6, or 8 cylinders. Additional scale for measuring the resistance of the Distributor Primary circuit.

An attached Timing Light and Timing Advance Unit to measure initial timing and degrees of engine timing advance while the engine is operating.

A large, (23 inch diagonal) easily readable oscilloscope for display ignition system patterns. The scope is provided with a transparent graticule of measuring secondary voltages up to 40,000 volts. The same graticule is used for measuring voltages up to 400 volts when primary ignition system or A.C. charging system patterns are viewed. Waveforms can be viewed in Superimposed, Raster or Display configurations.

A Coil Tester used in conjunction with the oscilloscope will test conventional or transistorized system or magneto ignition coils on or off the vehicle.

20-2.8 INFRARED ANALYZERS

Name: Allen CO/HC Infra-Red Emission Analyzer
Manufacturer: Allen Test Products Division, The Allen Group, Incorporated, Kalamazoo, Michigan 49007/ (616)345-8531
Model: 23-170 **Figure No.:** 20
Size: 38 in. H x 34 in W x 20 in. D **Weight:** 115 lb
Power Requirements: 115 VAC, 60 Hz
National Stock No.:

Figure 20-49. Allen's CO/HC Emission Analyzer.

Description: The Allen CO/HC emission analyzer utilizes a tailpipe probe and the NDIR analysis method to measure CO and HC. Its technical specifications follow:

Meters: 8 inch - Dual Scale
Hi-Scale = 0 to 10% CO
0 to 2000 PPM HC (per N Hexane)
Lo-Scale = 0 to 2.5% CO
0 to 500 PPM HC (per N Hexane)

Accuracy:

Hi-Scale = CO within 0.3% CO
HC within 60 PPM

Lo-Scale = CO within 0.075% CO
HC within 15 PPM

Response: 90% Reading in Max. 10 Secs.

Zero & Span Drift: Max. 2% Full Scale.

Calibration: Built-in Optical Calibration System provides rapid routine calibration. Calibration Gas Inlet Ports provided and adjustments readily accessible.

Optical System: Duplexed Dual Beam System.

Cell Windows: Sapphire and Quartz.

Exhaust Handling System:

- 30 ft. exhaust probe, polyurethane lined hose with stainless steel tip provides ruggedness required in garages.
- Teflon coats diaphragm pump for corrosion resistance.
- Self-draining water trap system.
- Dual particulate filters insure greater protection and accuracy.
- "Flow Indicator" on meter panel.

Name: Infrared Vehicle Exhaust Analyzer
Manufacturer: Beckman Instruments, Incorporated, Process Instruments Division, 2500 Harbor Blvd., Fullerton, California 92634/(714) 871-4848
Model: 590 **Figure No.:** 20-50
Size: 45 in. H x 23 in. W x 17 in. D **Weight:** 85 lbs.
Power Requirements: 115 VAC, 60/50 Hz
National Stock No.:

Figure 20-50. Beckman's Model 590 Infrared Vehicle Exhaust Analyzer.

Description: The Model 590 Infrared Exhaust Analyzer is designed for ease of operation for the garage and service station market. Its technical specifications follow:

Ranges: Hydrocarbons 0-2000 ppm
Carbon Monoxide 0-400 ppm
0-2%

Meters: High visibility 8" meter scales
Dual scales

Accuracy:

High Ranges:	Low Ranges:
0.3% CO	0.06% CO
60 ppm HC	12 ppm HC

Response Time: 90% reading in 5 seconds initial warm-up in less than 15 minutes. Warm-up from stand-by position in less than 5 minutes.

Calibration: Integral electronic calibration system provides convenient rapid routine calibration of the analyzer. Span gas capability

Ambient Temperature Range: 35°F to 110°F

Exhaust Sample Conditioning System:

- 25 ft. of sampling hose with flexible stainless steel probe
- High capacity sample pump
- Self-draining water trap
- Coarse particulate filter
- Low sample flow panel indicator

Exhaust Probe Length: 25 feet.

Name: Process Infrared Analyzer
Manufacturer: Beckman Instruments, Incorporated Process Instruments Division, 2500 Harbor Blvd, Fullerton, California 92634/(714) 871-4848
Model: 864 **Figure No.:** 20-51
Size: 9 in. H x 13 in. W x 21 in. D **Weight:**

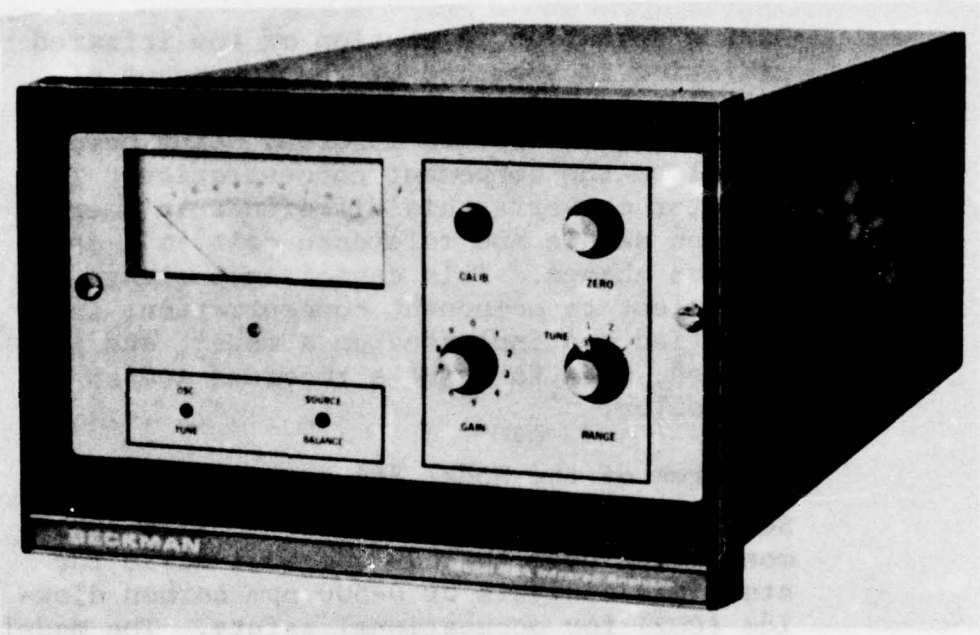


Figure 20-51. Beckman's Process Infrared Analyzer.

Description: The Beckman Model 864 Infrared Analyzer has been designed for accurate, reliable, continuous determination of a given chemical component concentration in a gaseous or liquid stream. An important option of the Model 864 is its internal span calibrator which conserves span gas for most applications, and also significantly lowers cost of operation.

The Model 864 produces infrared radiation from two separate energy sources. Once

produced, this radiation passes through a chopper which interrupts it 10 times/second, and then passes through optical filters to reduce background interference from other infrared absorbing components.

The infrared beams pass through two cells; one a reference cell containing a non-absorbing background gas, the other a sample cell containing a continuous flowing sample.

During operation, a portion of the infrared radiation is absorbed by the component of interest in the sample, with the percentage of infrared radiation absorbed being porportional to the component concentration. The detector converts this difference in energy between sample and reference cell to a capacitance change. This capacitance change, equivalent to component concentration, is amplified and indicated on a meter, and if desired, used to drive a recorder and/or controller.

Features of the Model 864 are:

Sensitivity: Permits carbon monoxide (CO) monitoring down to 1000 ppm full scale for stack gas analysis or 0-500 ppm carbon dioxide (CO_2) for occupational safety. The Model 864 can also measure nitric oxide or sulfur dioxide down to 2000 ppm full scale for source emission analysis.

Selectivity: The 864 is designed so that a 10% concentration change of CO_2 or H_2) vapor will affect CO readings by no more than 10 ppm or 1% of full scale on the most sensitive range.

Accuracy: The accuracy of the Model 864 is rated at 1% of full scale. In process application, where yield is related to accuracy, a 2% or 5% IR Analyzer doesn't begin to compare with the 864. In surveillance or effluent quality enforcement, high accuracy eliminates uncertainty and possible error.

Selectable Speed of Response: The Model 864 has 90% response in 0.5 second, an important feature for high speed data monitoring. For closed loop control capability, response can be slowed to 90% in 2.5 seconds with the flick of a switch.

Gas or Liquid Analysis Capability: Permits one analyzer for use with gas or liquid samples. Minimizing training and back-up parts required by maintenance departments.

Universal Outputs: The 4 voltage and 2 current outputs (optional) on the 864 make it compatible with virtually all modern recorders.

Linear Output: Integration of data is frequently required in batch or process applications; however, since all IR Analyzers behave according to Beer's Law, their output is non-linear as a function of concentration. A non-linear signal cannot be integrated accurately; so to permit accurate data integration, an optional circuit linearizer is available which plugs directly into the instrument.

Name: Infra-red Exhaust Performance Analyzer
Manufacturer: Sun Electric Corporation, 3011 East Route 176, Crystal Lake, Illinois 60014/(815) 459-7700
Model: U-912-1 **Figure No.:** 20-52
Size: 21 in. W x 25 in. D x 30 in. H **Weight:** 110 lbs
Power Requirements: 120 VAC, 60 Hz
National Stock No.:

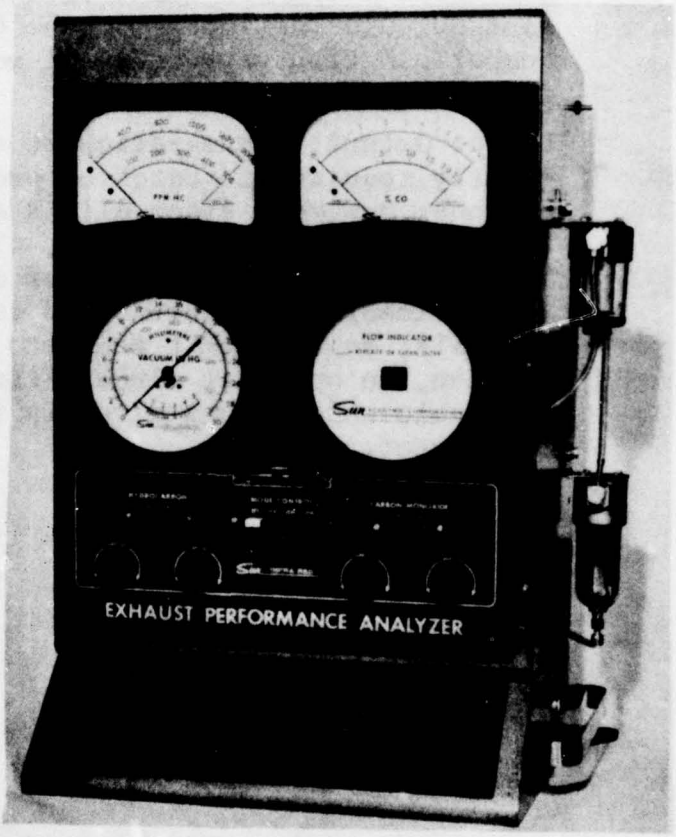


Figure 20-52. Sun's Infra-Red Exhaust Analyzer.

Description: The Sun Exhaust Emission Tester (Model U-912-I) is a solid-state, non-dispersive Infra-Red exhaust analyzer. It measures levels of Hydrocarbons (HC) and Carbon Monoxide (CO) in the exhaust of an internal

combustion engine. Dual scales on each meter provide over-all measurement ranges between 0-500 and 0-2000 parts-per-million (ppm) for HC, and 0-2.5% and 0-10% for CO. The single-probe sampling system permits easy and rapid testing.

Levels of HC can be read between 0-2000 ppm and 0-500 on separate color-coded scales. The same arrangement permits reading CO levels between 0-10% and 0-2.5%. Each meter is completely adjustable for zeroing and span-set. All other adjustments are made at the factory. A low flow indicator light on the front panel is illuminated when the filters need cleaning or changing, or when the sample system becomes blocked. The system warms up and is ready for use in only five minutes, with increased zero drift rates. After 15 minutes of warm-up, the zero drift rate is less than $\pm$5% over a 24-hour period. The tester responds to 95% of each reading within the first seven seconds after the probe is inserted into an exhaust stream. The unit provides a cross-sensitivity level of less than 0.1% of full-scale reading on the CO meter measured against a 15% CO_2 sample. The complete system is accurate over-all to $\pm$2-1/2% of full-scale reading on either meter and is essentially unaffected by fluctuations in line voltage. Electronic "noise" affects the tester less than $\pm$1/2% of full-scale reading on either meter.

The HC/CO Analyzer can be electro-mechanically calibrated and does not require gas calibration. However, the unit has the capability of being calibrated with a certified span gas should local, state and/or Federal legislation so dictate. If gas calibration is desired, the gas calibration kit, No. 120-223, is required to connect the span gas container to the tester.

The sampling handling system consists of a scainless steel tailpipe probe, a 25-foot polyurethane hose, a self-draining water system, a dual-filter sample system to push the sample through the emission analyzer. The pump/filter combination ejects condensed moisture into the atmosphere, rendering the system self-draining.

20-2.9 VIBRATION SYSTEMS

20-2.9.1 Vibration Measurement Systems

Name:	TK-80 Portable Test and Diagnostic Kit
Manufacturer:	Bently Nevada, P.O. Box 157, Minden, Nevada 89423/(702) 782-2255
Model:	TK-80 Figure No.: 20-53
Size:	3.9 in. H x 3.5 in. W x 6.2 in. D Weight: 2 lbs.
Power Requirements:	±27 VDC (6 nine volt alkaline batteries)
National Stock No.:	

Figure 20-53. Bently Nevada's TK-80 Vibration Measurement Kit.

Description: The TK-80 is a compact machinery diagnostic instrument that measures vibration displacement and velocity. The instrument contains a tunable filter that permits a specific RPM

signal to be passed or rejected. In the Direct mode, the composite vibration signal (all RPM) is passed for measurement.

Shaft Vibration - Uses a non-contacting proximity probe (one probe is included with the TK-80) as the transducer. The TK-80 has an internal proximitor to drive the probe, or you can take the signal directly from an external proximitor. The meter reads out in peak-to-peak mils displacement.

Shaft Position - Shaft relative position information is available. Just depress the probe gap switch and compare the reading with the known installation gap.

Casing Vibration - A velocity seismoprobe is provided. Readout is switch selectable to read in peak inches per second or peak-to-peak mils.

Vibration Frequency - Band pass and band reject filter functions are standard.

Outputs - Both filtered and unfiltered transducer signals are available for use with other diagnostic equipment, such as oscilloscopes, recorders, etc.

The standard TK-80 includes one 0.300" eddy current proximity probe and extension cable and one velocity seismoprobe with cable. It is a more useful instrument when teamed with a mini-oscilloscope. Technical specifications are as follows:

- Input Signal
  - A. Position or vibration displacement signal from 190 or 300 proximity probe connected to TK-80 internal proximitor, or from external proximitor calibrated at 200 mv/mil (4 v/mm).
  - B. Velocity signal from velocity seismoprobe calibrated at 500 mv/in/sec (50 mv/mm/sec)

- Meter Indication

  A. Battery condition
  B. Gap voltage of proximity probe
  C. *Vibration displacement in peak-to-peak mils (micrometers)
  D. *Velocity in peak in/sec (mm/sec)

- Filter RPM Range
  200 to 220,000 rpm in three ranges

- Filter Attenuation
  Filter Q = 15 (bandwidth = 6.6%)

- Accuracy

  Meter: 3% of full scale
  Filter Tuning: 2% of tuning knob setting

- Output Available

  A. Proximity probe input signal, buffered and filtered per filter control setting.

  B. Seismoprobe input signal, buffered and normalized by a scaler circuit having gain of 0.2 (integrated to displacement if so set at INPUT selector) and filtered per filter control setting.

*Tunable filter permits observing peak of composite signal or selection of specific rpm to be passed or rejected.

Name: Vibration Detector

Manufacturer: Columbia Research Laboratories, Incorporated, MacDade Blvd. and Bullens Lane, Woodlyn, Pennsylvania 19094/(215) 532-9464

Model: VM-103 **Figure No.:** 20-54

Size: **Weight:**

Power Requirements:

National Stock No.:

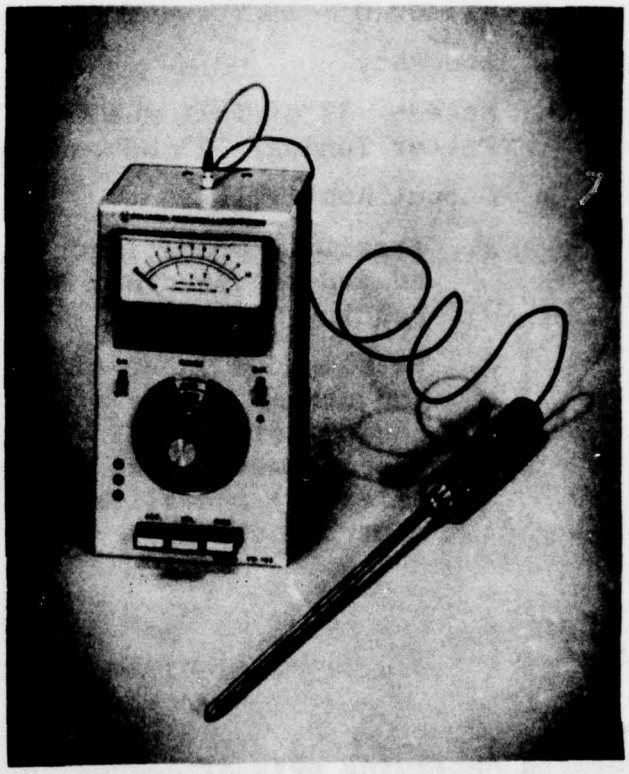


Figure 20-54. Columbia's Vibration Detector Model VM-103.

Description: The Columbia Vibration Detector Model VM-103 is useful for periodic routine vibration checks of industrial machinery. It will detect any change in vibration signature and give an early warning (E-W) of impending trouble. An increase in vibration levels can be an indication of unbalance, misalignment, faulty gears, poor belt drives, bad bearings, etc.

The Columbia "E-W" procedure is extremely simple. You apply the probe of the Columbia Model VM-103 to any rotating machinery, and determine the normal working vibration level or vibration signature of the particular machinery. The early onset of a malfunction will produce a detectable deviation from the probably specific trouble area while the machinery is still productive. The VM-103 instrument is useful for measuring displacement, velocity and acceleration.

Name: Universal Quartz Transducer Kit
Manufacturer: PCB Piezotronics, Incorporated, P.O. Box 33, Buffalo, New York 14225/(716) 684-0001
Model: Kit No. 909A **Figure No.:** 20-55
Size: **Weight:**
Power Requirements:
National Stock No.:

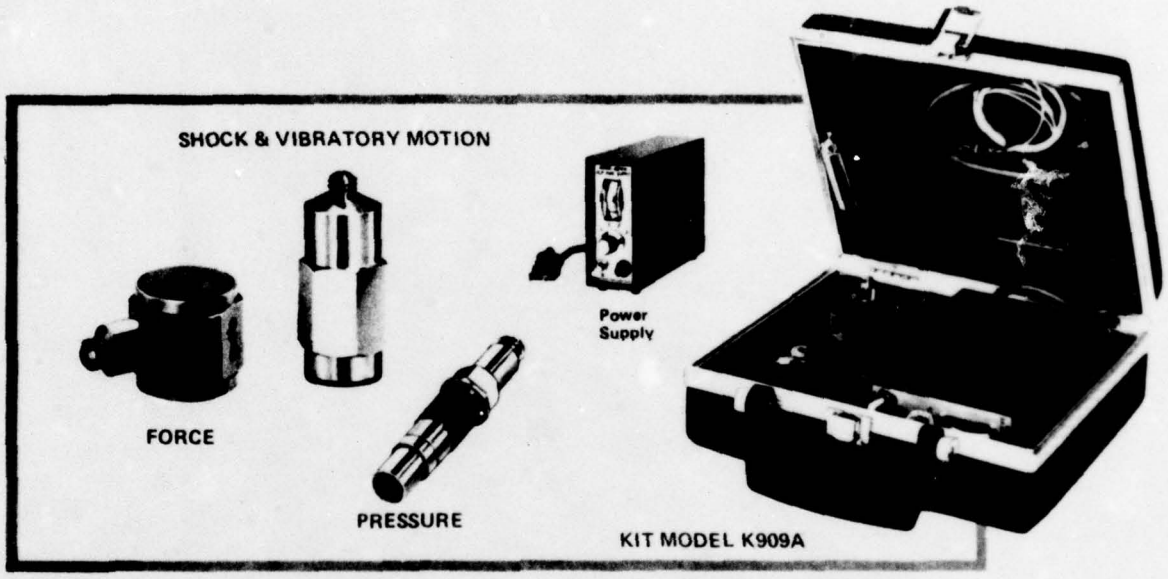


Figure 20-55. PCB Piezotronics' Quartz Transducer Kit.

Description: The 909A universal kit adapts an oscilloscope or analyzer for mechanical measurements of dynamic pressure, force and shock or vibratory motion. Each of the three quartz transducers involved cover a measuring range of 10,000 to one. Coupling to digital oscilloscopes facilitates quantitative measurements of transient or oscillating mechanical phenomena.

Packaged in convenient assembled kit form, the transducers are supplied complete with cables, hardware and accessories for normal

operation. The Model 909A kit includes an improved low-noise (200 uV), four-channel line power unit for transducer excitation. A versatile impulse-force test hammer is included for testing behavior, detecting faults and diagnosing troubles in mechanical structures. Standard transducer cables are ten feet long.

The 909A Quartz Transducer Kit can also instrument sinusoidal, step, impulse and random forcing functions and measure data for computing compliance stiffness, mechanical impedance, resonances and mode shapes.

Technical specifications are:

Range - psi, lb, g 0.1 to 1000
Resolution - psi, lb, g 0.02
Maximum Measurand - psi, lb, g 5000
Sensitivity - mV/unit 10.0
Frequency Response ($\pm$5%) Hz 0.5 to 10,000
Linearity (BFSL) - %
Output Voltage - volt $\pm$10
Output Impedance - ohm 100

20-2.9.2 Bearing Analysis Systems

Name:	Acoustic Emission Detector
Manufacturer:	Allison Laboratories, Incorporated, 911 Prairie Trail, Austin, Texas 78758/(512) 836-5160
Model:	705 Figure No.: 20-56
Size:	8.5 in. L x 3 in. H x 4.4 D Weight: 5.5 lbs.
Power Requirements:	4 Batteries (NEDA 1604 furnishing 18 VDC)
National Stock No.:	

Figure 20-56. Allison's Acoustic Emission Detector.

Description: The Model 705 is a portable battery operated instrument for industrial use in bearing maintenance. The light weight and simplicity of operation make it suitable for use by unskilled personnel. All measurements are made during operation and it is unnecessary to shut down adjacent machines since they normally do not affect the measurement of acoustic emission. The Model 705 is designed to incorporate both visual and aural readouts. The wide range of measurement by meter reading is supplemented by monitoring the noise of the bearing (in the same manner as used in AM radio). The sounds indicate

the difference between actual mechanical failure and lack of lubrication or foreign material entering the lubricant. The detector is designed to be used with bearings operating at speeds above approximately 500 RPM and averages the value of each shock pulse as the bearing rotates. The instrument has additional outputs (AC and DC) which may be connected to recorders (DC) to monitor the bearing over an extended period of time or an oscilloscope (AC) to observe the characteristics of the signal in relation to the type of failure.

The Model 705 also has a peak reading feature which permits the measurement of bearings whose rotational speeds are low - down to 1 RPM. The instrument collects each shock pulse and stores the information so that any defect which produces even one pulse of acoustic emission will be acquired and held for measurement. This feature is particularly valuable in maintaining slow speed machinery such as found in processing of paper, food, aggregates, grain plus many other slow speed operations. A battery saver is included which makes it impossible to leave the power on and run down the battery.

Technical specifications are:

Measuring Range:	0 to 50 dB	
Meter:	0 to 10 dB - linearity $\pm$0.5 dB	
Output:	DC (full scale):	10 VDC into 100,000 ohms
Output:	AC (full scale):	0.20 VRMS into 100,000 ohms

Name: Bearing Analyzer
Manufacturer: Mechanical Technology Incorporated, 968 Albany Shaker Road, Latham, New York 12110/ (518) 785-2211
Model: BDI-100 Figure No.: 20-57
Size: Weight:
Power Requirements: 115 VAC, 60 Hz
National Stock No.:

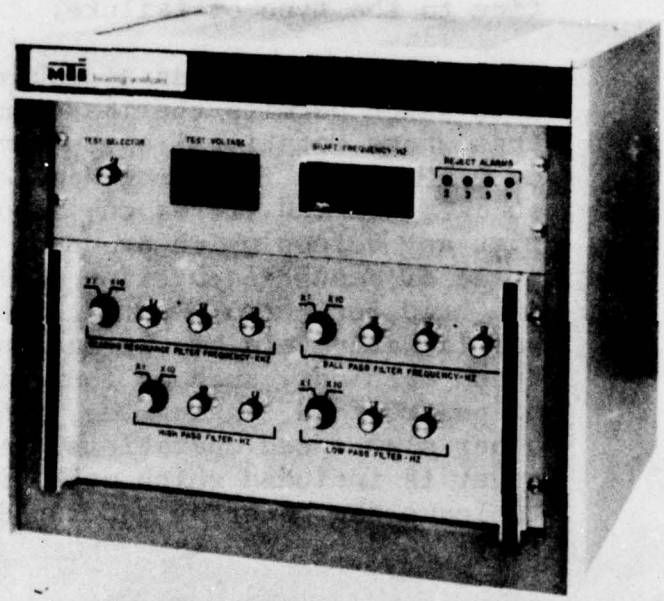


Figure 20-57. MTI's Bearing Analyzer.

Description: The Model BDI-100 Bearing Analyzer is a special purpose instrument used to test or monitor bearings for faults or indications of impending failure. The BDI-100 uses vibration signals that emanate from rolling element bearings when they are rotating under normal operating conditions. In R&D programs sponsored by NASA and other Government agencies, it has been found that resonant frequency modes of rolling element bearings are excited in normal running conditions. These natural resonances are rich in

information content about the condition of bearing elements, i.e., races, rolling elements, and cage. The BDI was designed to pickup bearing resonance signals, isolate them from other machinery noise and process this selected information. This principle has been identified as the High Frequency Resonance Technique (HFRT). The BDI-100 makes use of new but well founded principles for acquiring bearing information that has previously been extremely difficult and costly to obtain. A piezoelectric accelerometer is used to sense bearing signals. This accelerometer should be mounted as close to the monitored bearing as possible. Mounting directly on the bearing race is probably the most advantageous, however, the HFRT signals can be picked up on housings with normal bearing fits and even through two or three mounting arrangement interfaces. The accelerometer signals are amplified and filtered in the BDI-100 to isolate the desired bearing resonance signal. An envelope detector is used to extract important bearing information and the detected signals are then filtered and processed to provide digital, numerical data.

The BDI-100 features:

- Digital panel meter displays
- Digital speed indicator
- "Dial-In" diagnostic signal processing
- Numerical readouts for bearing behavior classification based on nine signal processing methods
- Conveniently located oscilloscope connections
- "Go" - "No-Go" warning light array with dial level adjustments
- Calibration test with built-in signal generator.

Name: Shock Pulse Meter
Manufacturer: Testing Machines Incorporated, 400 Bayview Avenue, Amityville, Long Island, New York 11701/(516) 842-5400
Model: SPM 43A Figure No.: 20-58
Size: Hand-Held
Power Requirements: Batt
National Stock No.:

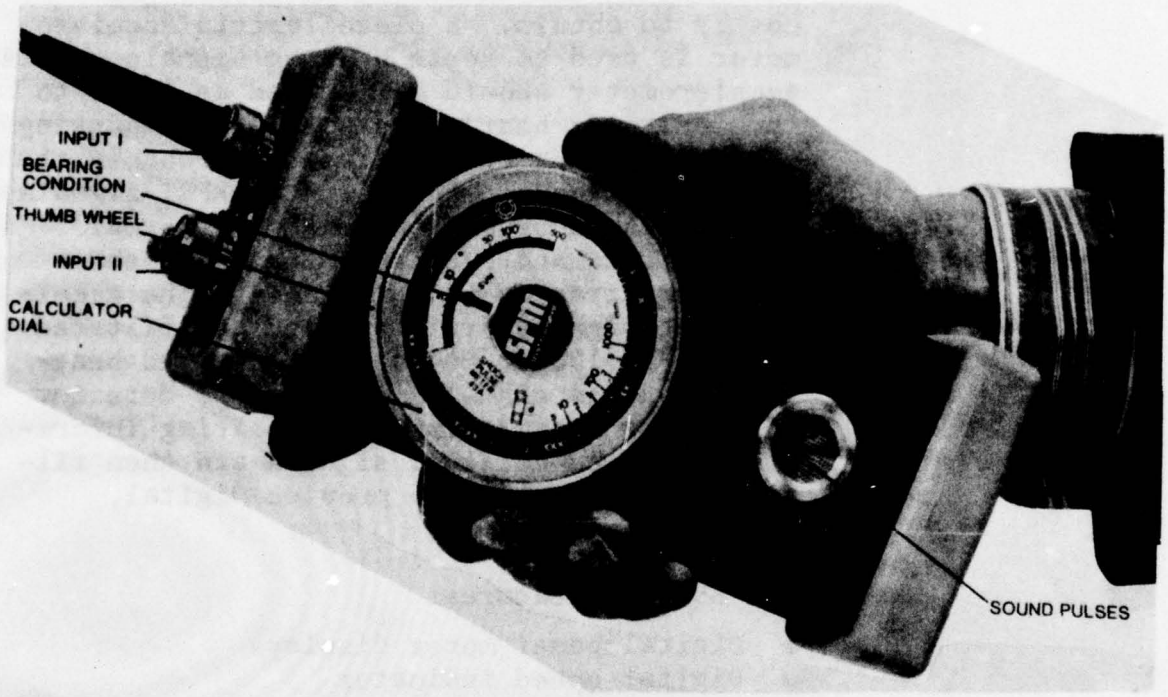


Figure 20-58. SPM Instrument's Model 43A Shock Pulse Meter.

Description: The SPM 43A instrument is manufactured by SPM Instrument AB, Sweden and sold by Testing Machines, Incorporated in the U.S. The SPM measuring method is effective on all types of machinery and systems containing anti-friction bearings. A tuned piezoelectric transducer is available (SPM 10777) in probe form to enable measuring of bearing condition directly without preparatory work on the bearing housing. Standard transducers use quick connect adapters installed on the bearing housing. A special leak detection microphone (10474) is also available

to enable use of the instrument for measuring leaks and cavitation in systems containing liquids, gases, vapor or steam. The principle of operation is as follows:

- The SPM Method relies on the fact that damage, contamination and other defects in anti-friction bearings will cause mechanical impacts. The magnitude of these impacts is a measure of the bearing condition.

  The impact within the bearing will set up a shock wave the magnitude of which is only dependent on the impact velocity, i.e., size of damage and size and speed of the bearing. The shock wave is propagated through the bearing housing and the wave front gives an indication of the defect through the contact point.

- When the pressure wave or shock pulse hits the transducer a dampened reasonant oscillation is set up in the transducer. The amplitude increase of the resonant oscillation is determined by the pressure wave front and is thus an indirect measure of the impact velocity. This measurement is not influenced by size or design of the machinery or any machine vibrations.

- Transducer signals are processed in the Shock Pulse Meter 43A. The shock wave caused by a bearing defect is transformed into analog electrical pulses. These pulses are then compared to a threshold level manually set with a thumb wheel. Damage exceeding the threshold level will cause short sound pulses of a constant volume, the frequency of which are an indication of bearing condition. The threshold level is then adjusted until no sound pulses are heard. The bearing condition is then read directly from the dial.

- By means of the calculator dial, the instrument can be preprogrammed with respect

to bearing diameter (d) and speed (n). Thus, the relative magnitude of damage and consequently the actual operational condition of the bearing can be read directly on the instrument.

Name: T700 Bearing and FOD Monitor

Manufacturer: General Electric Company, Aircraft Engine Group, 1000 Western Avenue, Lynn, Massachusetts 01910/(617) 954-0100

Model: T-700 Engine (prototype) Figure No.: 20-59

9 in. W x 5 in. H x 6.5 in. D Weight: 6.5 lbs.

Power Requirements: 115 VAC, 400 Hz

National Stock No.:

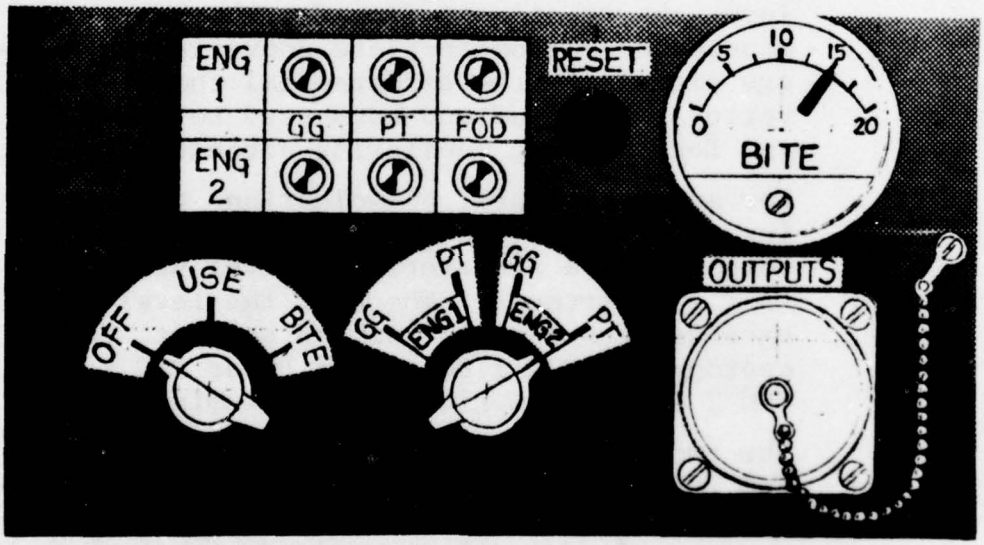


Figure 20-59. GE's Panel Layout - T-700 Bearing and FOD Monitor.

Description: The T-700 engine bearing and foreign object damage monitor is designed for continuous operation in the aircraft. The instrument accepts signals from accelerometers incorporated in the engine adjacent to the major engine bearings. A warning lamp is displayed when bearing distress or foreign object damage has exceeded a predetermined limit. A meter on the face of the instrument will display analog indications of the condition of each.

bearing monitored. The instrument also incorporates a built-in test circuit that enables the operator to check for proper operation and calibration.

The front panel of the monitor contains a power on-off switch, a neon power lamp, a fuse holder, a USE-BITE mode switch, a four-position display selector switch, six warning lamps, a reset switch, a 0110 analog indicator, and a capped 24-pin output connector. This connector can also be used to trigger an alarm in the aircraft cockpit whenever any of the limits have been exceeded.

Input charge signals from four bearing-mounted accelerometers are converted to voltage signals by the differential charge converters, buffered and connected to two FOD and four bearing monitoring circuits.

For automatic warning indication, the bearing condition signals of either engine are compared to a predetermined level programmed in the instrument. Whenever the level is exceeded for a period of ten seconds, the appropriate ENG 1 GG, ENG 1 PT or ENG 2 GG, ENG 2 PT WARNING LIGHT will illuminate.

The two warning lights labeled ENG 1 FOD and ENG 2 FOD will automatically illuminate whenever gas generator rotor impact exceeds a predetermined level programmed within the instrument. The warning light will remain illuminated until 400 Hz power is removed or the engine is shut down. If power is interrupted or the engine is subsequently restarted, the light will not illuminate unless another impact is encountered.

A reset switch is provided for manually resetting any circuit that displays a warning. All circuits may be tested for normal operation using the BITE mode. Since the BITE signals are large enough to cause all warning lamps to light, it will be necessary to push the reset switch to re-establish normal "USE mode" monitor operation.

20-2.9.3 Vibration Analyzers

Name:	Portable Vibration Analyzer
Manufacturer:	B&K Instruments, Incorporated, 5111 West 164th Street, Cleveland, Ohio 44142/(216) 267-4800
Model:	3513/S
Size:	18 in. L x 13 in. D x 6.5 in. H
Power Requirements:	Rechargeable battery
National Stock No.:	

Figure No.: 20-60
Weight: 25 lbs.

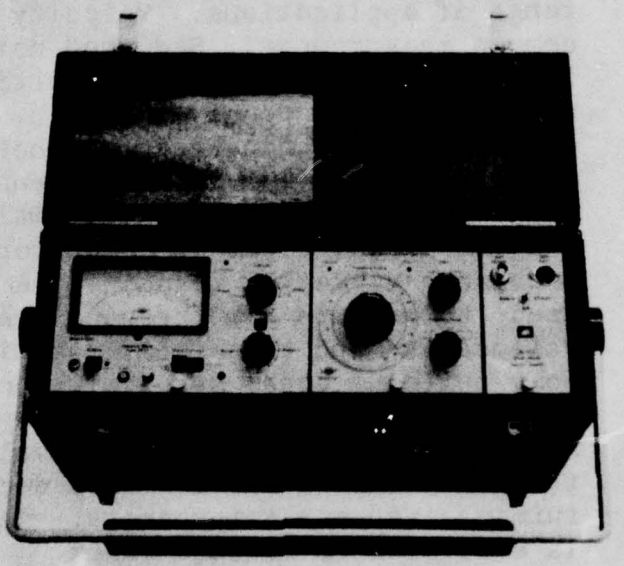


Figure 20-60. B&K Instruments' Portable Vibration Analyzer.

Description: The 3513/S Portable Vibration Analyzer is a high quality analyzer designed for both labatory and field use. The component 2511 Vibration Meter and 1621 Tunable Filter are housed in a rugged carrying case along with an accelerometer, connecting cable and rechargeable battery pack. The 3513/S has application in major areas such as: 1) quiet product development, 2) environmental noise

control, 3) machine condition monitoring, and 4) evaluations of the effectiveness of vibration isolators.

The 2511 Vibration Meter is a versatile instrument which is used in conjunction with a small piezoelectric pickup to measure vibration in terms of acceleration, velocity or displacement. It is fully calibrated in both metric and English units. Readout is in RMS or peak-to-peak amplitude with added capability to hold the maximum level that occurs during a measurement.

The ability to read out in three vibration parameters makes the 2511 useful for a wide range of applications. Velocity is the most common measurement. Radiated noise level from vibrating panels is proportional to the velocity amplitude of vibration. Damage potential to machinery is a function of the kinetic energy ($1/2\ MV^2$) that must be dissipated. Therefore, preventive maintenance programs require periodic monitoring of machinery vibration velocity. Amplitude is used to measure low frequency mechanical deflections and to balance rotating shafts. Some building codes set limits on the vibration amplitude caused by rotating equipment. Acceleration is necessary to evaluate high frequency vibrations commonly encountered in turbines and air compressors. Acceleration is also used to measure shock.

The 1621 Turnable Filter is used in fault-finding to identify dominant frequencies and to record vibration signatures for comparison with those taken at earlier dates. The optional Model 2306 Portable Level Recorder is available for hard copy documentation.

The sensitivity of the 2511 Vibration Meter is:

Mode	Full Scale Sensitivity	Frequency Range
Acceleration	0.01-100 m/s^2 0.001-10 g	0.3 Hz to 1 kHz +
Velocity	10;100;1000m/s 1.0;10;100 in/s	1 Hz to 1 kHz +

Mode	Full Scale Sensitivity	Frequency Range
Displacement	0.1;1.0;10 mm 0.01;0.1;1.0 in	1 Hz to 275 Hz

Name: Vibration Analyzer and Dynamic Balancer
Manufacturer: Metrix Instrument Company, 5760 Rice Avenue, P.O. Box 36501, Houston, Texas 77036/(713) 668-2386
Model: 5115B Figure No.: 20-61
Size: 4.7 in. H x 13.3 in. W x 15.7 D Weight: 18 lbs.
Power Requirements: Rechargeable Battery (115/230 VAC, 50/60 Hz)
National Stock No.:

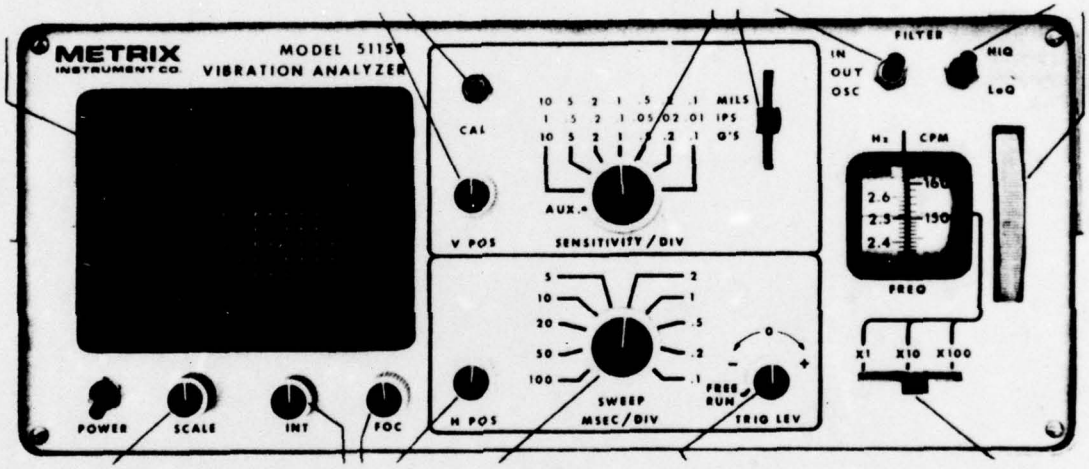


Figure 20-61. Metrix Instrument's Vibration Analyzer.

Description: Consisting of a rugged vibration pickup and a lightweight portable indicator unit, complete with integral oscilloscope, the Model 5115B Vibration Analyzer measures the amplitude and frequency of vibration displacement, velocity or acceleration.

A continuously variable narrow band filter provides the means to analyze vibration in the frequency domain (amplitude versus frequency). The filter dial is graduated both in Hz and CPM, eliminating the need to convert from one to the other. In addition, with filter out, the integral oscilloscope allows vibration analysis in the time domain

(amplitude versus time), which is invaluable for observing impulse phenomena, beat frequencies and phase relationships of fundamental and harmonic frequencies.

Other features include X and Y input jacks for displaying Lissajous patterns of horizontal and vertical components of vibration; a signal output jack, strobe sync output, external sweep trigger input and an auxiliary jack for powering and receiving signals from external units.

Optional accessories include an oscilloscope camera for taking pictures of vibration displacement, velocity or acceleration in the frequency band 0.8 Hz to 1700 Hz 950 CPM to 100,000 CPM).

Name: Portable Vibration Analyser
Manufacturer: Vibro-Meter S.A., Fribourg, Switzerland/ Vibration Sales and Service, P.O. Box 5851, Amity Sta., New Haven, Connecticut 06525/ (202) 389-1527
Model: VM-3/C Mk II Figure No.: 20-62
Size: 11.8 in. D x 5.1 in. H x 12.2 W Weight: 9.3 lbs.
Power Requirements: Rechargeable Batteries/110-250 VAC, 50-400Hz
National Stock No.:

Figure 20-62. Vibrometer S.A.'s Portable Vibration Analyser.

Description: The Vibro-METER Model VM-2/C Mk II vibration analyser offers the possibility of operation with both piezoelectric (acceleration) and electromagnetic (velocity) type vibration pick-ups of various sensitivities without the need for recalibration. In addition, a high precision readout in terms of velocity, displacement or acceleration over an exceptionally wide range is given on the built-in indicator.

The measuring frequency range can be matched to that of existing vibration measurement equipment by the simple action of plugging in up to four standard Vibro-Meter high or low pass filter modules. For increased flexibility the combination mode of these filters can be varied by means of an internal selector switch.

The additional facility for the connection of an external filter permits the analyzer to be used with, for example, standard 1/3 octave filters.

For narrow-band analysis purposes, a built-in fully calibrated constant percentage band-width filter, tunable over the full frequency range of the instrument, is provided. The analyser may be operated in the field from its built-in battery pack, which is automatically charged, either by using the analyser's main power or by means of the battery charge facility provided.

The Model VM-3/C instrument can be used for vibration monitoring and analysis by users of turbines, compressors, pumps, machine tools, motors, generators, etc. Output characteristics for the VM-3/C vibration analyser include peak acceleration, peak velocity or peak-to-peak displacement for piezoelectric transducers and peak velocity or peak-to-peak displacement for electromagnetic transducers. The measuring range of these parameters is:

Peak Acceleration:
0.3 1 3 10 30 100 g

Peak Velocity:

0.3	1	3	10	30	100 cm/s
0.12	0.4	1.2	4	12	40 in./s

Peak-to-Peak Displacement:

0.3	1	3	10	30	100 x 0.1 mm
0.12	0.4	1.2	4	12	40 x 0.01 in.

20-2.9.4 Vibration Monitoring and Balancing Systems

Name:	Modular Vibration Monitoring System
Manufacturer:	Bell and Howell, CEC Division, 360 Sierra Madre Villa, Pasadena, California 91109/ (203) 796-9381
Model:	CEC 4000
Figure No.:	20-63
Size:	19 inch Rack Mount Case
Weight:	
Power Requirements:	115 VAC 50/60 Hz
National Stock No.:	

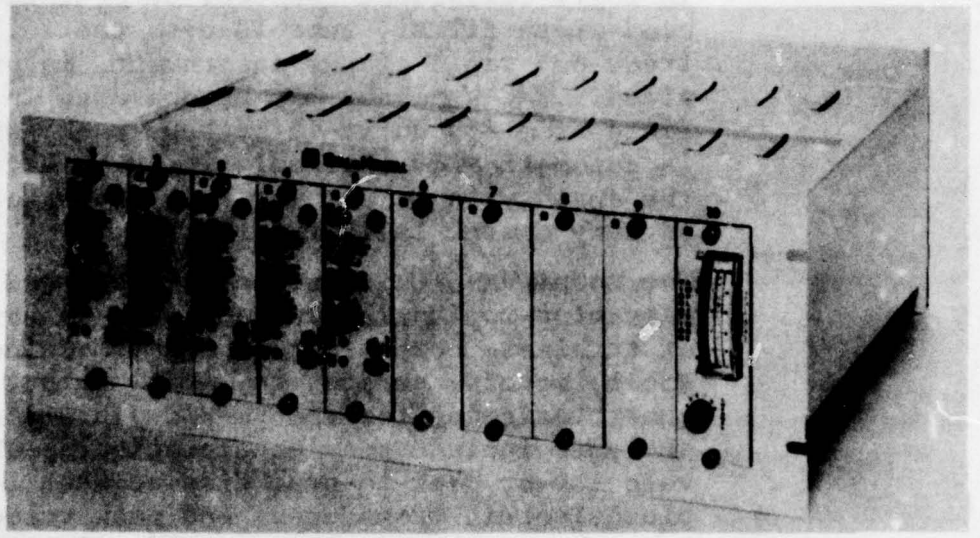


Figure 20-63. Bell and Howell's CEC 4000 Monitoring System.

Description: The CEC 4000 Modular Vibration Monitoring System consists of three basic modular components: amplifier module, indicator-meter and fitted case. The amplifier module is the heart of the system. Standard options permit a wide choice in adapting the system to a variety of needs. Each amplifier module contains an individual power supply to increase total system reliability - all channels operate on a completely independent basis.

The Modular Vibration Monitoring System is designed for continuous on-line monitoring of industrial equipment in any environment where remote measurement of operating parameters is desirable. It is engineered for simple expansion. Additional amplifier modules can be integrated into the system while on-line. Down time for repair or modification is minimized.

The CEC 4000 system features:

- Self-calibration for matching amplifier gain to transducer sensitivity.
- Charge amplifier for piezoelectric accelerometer input.
- AC analog output for oscilloscope or analyzer.
- Alarms with visual trip-level indicators and trip-level settings.
- Active high-pass, low-pass or band-pass filters for observing discrete frequencies of interest.

The basic amplifier module includes alarm-indicator lights, alarm-set switches, function select switch, mode select, range select, calibration adjust and, sensitivity adjust. The CEC 4000 will accept signal input from velocity transducers, piezoelectric accelerometers, and piezoelectric accelerometers with integral electronics. Its modules have a frequency response of:

Linear Mode (Velocity of Accelerometer input): $\pm$5.0% from 5 to 5000 Hz when referenced to 100 Hz.

Integrating Mode (Velocity Input): Displacement output of $\pm$5.0% from 59 to 2000 Hz when referenced to 100 Hz (limited at 150 ips velocity).

Integrating Mode (Acceleration Input): Velocity output of $\pm$5.0% from 10 to 2000 Hz when referenced to 100 Hz (limited at 150 g's peak).

Integrating Mode (Acceleration Input): Displacement output of ±5.0% from 10 to 2000 Hz when referenced to 100 Hz (limited at 150 g's peak.

Name: Unicel II Series 8800 Monitor System
Manufacturer: IRD Mechanalysis, Incorporated, 6150 Huntley Road, Columbus, Ohio 43229/(614) 885-5376
Model: 8800 Figure No.: 20-64
Size: Weight:
Power Requirements:
National Stock No.:

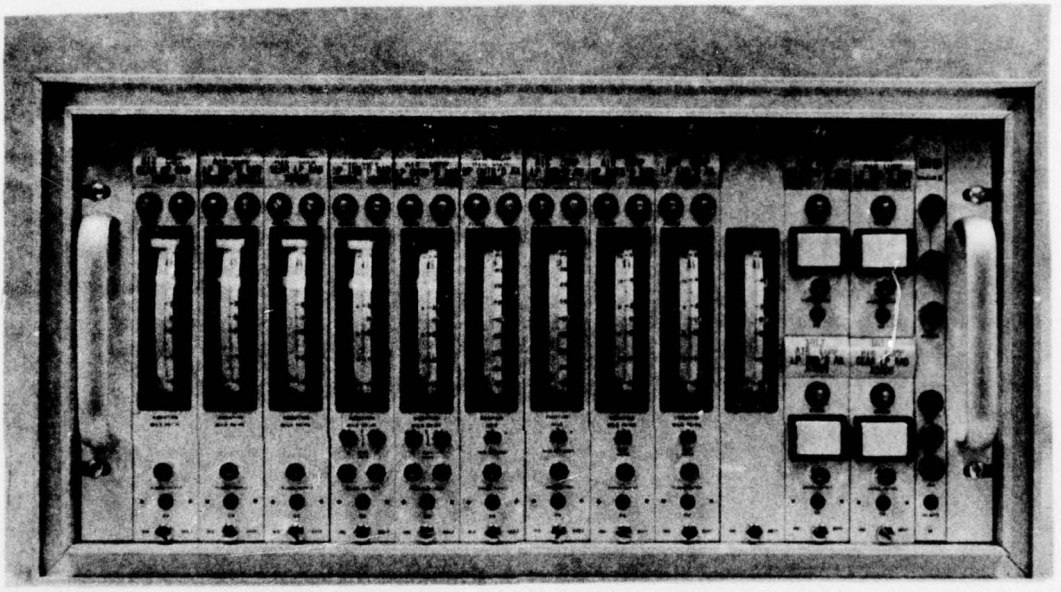


Figure 20-64. IRD Mechanalysis' Monitor System.

Description: Unicel II Series 8800 Monitor System provides reliable, full-time protection against a variety of machinery faults. Up to 12 single or dual channel interchangeable modules monitor vibration, rotor position, speed temperature, pressure and other parameters utilizing a choice of transducers. System includes alarm and trip indicators and relays for each channel, first out indication, trip override, system test and alarm, individual computer outputs and many other features.

Frequency and Amplitude Ranges: Choice of ranges and parameters for all types of critical machinery.

Name: Balancing Machine and Balancer
Manufacturer: IRD Mechanalysis, Incorporated, 6150 Huntley Road, Columbus, Ohio 43229/(614) 885-5376
Model: B25 Balancing Machine Figure No.: 20-65
Series 230 Balancer Weight:
Size:
Power Requirements:
National Stock No.:

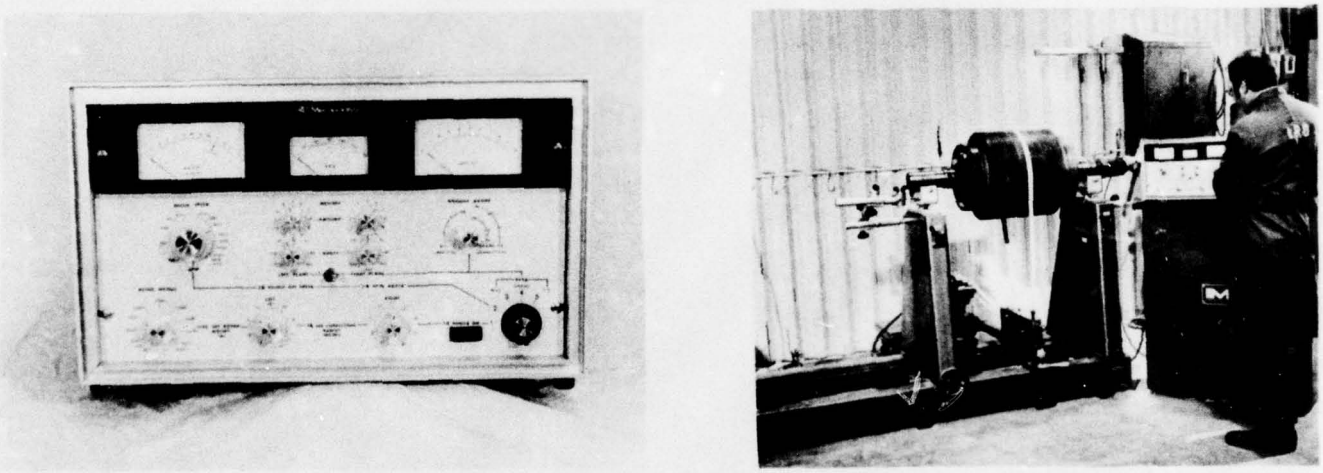


Figure 20-65. IRD Mechanalysis' B25 Balancing Machine and 230 Balancer.

Description: The IRD B25 Balancing Machine, with portable or dedicated instrumentation, provides a complete system for balancing a wide variety of rotors.

A unique work support suspension system has a natural frequency well below balancing speed independent of the rotor weight, assuring precision balancing over the complete balancing speed range. Features include quick setup, rapid change of bearing span, variable speed drive and antifriction bearing assemblies. No special foundation is required - machine base mounts directly to existing shop floor, standard railroad spur or track. The Model B25 has a weight

capacity of from 1 to 2500 pounds.

The Series 230 Balancer, with programmed front panel instructions, is ideally suited for job shop and motor repair balancing applications. It provides fast, accurate balancing without calibration runs, trial weights or strobe light. Symmetrical rotors, where corrections planes are between bearing supports, can be balanced with minimum number of spin-ups, often on first run.

Name: Trim Balance - Vibration Analysis System
Manufacturer: Endevco, Rancho Viejo Road, San Juan Capistrano, California 92675 (714) 493-8181
Model: 68100 Figure No.: 20-66
Size: 19 in. W x 5.3 in. H x 18 in. D Weight:
Power Requirements:
National Stock No.:

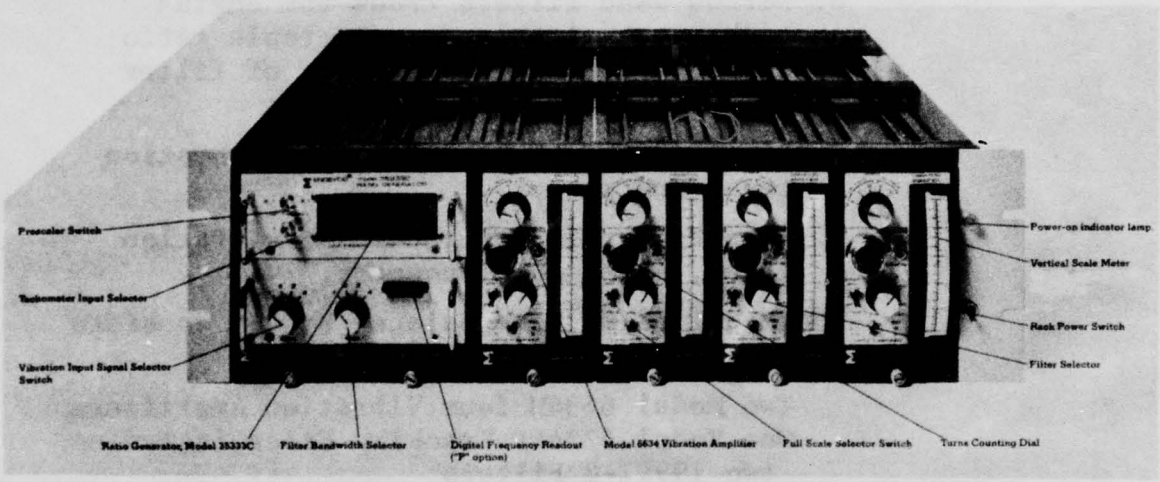


Figure 20-66. Endevco's Vibration Monitoring System.

Description: The Endevco Model 68100 is an instrumentation system for vibration monitoring, analysis, and balancing. It is a compact two-channel system compatible with piezoelectric accelerometer and velocity vibration transducer inputs and displays overall and filtered vibration levels, phase, and frequency. It features:

1. Two channels for analyis, and two-plane balancing.
2. Accepts piezoelectric accelerometer or velocity pickup inputs.
3. Displays overall vibration levels in terms of displacement, velocity, or acceleration.

4. Provisions for three fixed filters per channel (high pass, band pass, etc., as specified by engine manufacturer) in the overall display.

5. Accepts standard engine tachometer signals and one per rev phase reference signal.

6. Narrow band filters track the engine tachometer signals or selectable ratio thereof with digital display of filter center frequency.

7. Displays narrow band filtered vibration level and phase.

8. Output signals for recording vibration level, phase and frequency.

The Model 68100 Trim Balance System consists of the following components:

Two Model 6634M four Vibration Amplifiers
One Model 6726EP Tracking Filer including:
 two 19997-2 Filters
 two 17625-2 Amplitude Detectors
 two 18270 Phase Detectors
 one 19726 Frequency Detector
 one 35333C Ratio Generator
Two Model 6631M7 Dual Meter Modules
One Model 4948 Rack Adapter
One Model 20226 Cable Assembly (provides all interconnections).

All input and output mating connectors (excluding BNC) are included.

Name:	Helicopter Main and Tail Rotor Balancer
Manufacturer:	Chadwick-Helmuth Company, Incorporated, 111 East Railroad Avenue, Monrovia, Calif. 91016/(213) 358-4567
Model:	177M-6 Figure No.: 20-67
Size:	15.5 in. L x 6.5 in. W x 5.5 in. H Weight: 9 lbs.
Power Requirements:	12 or 28 VDC
National Stock No.:	4920-00-235-4540

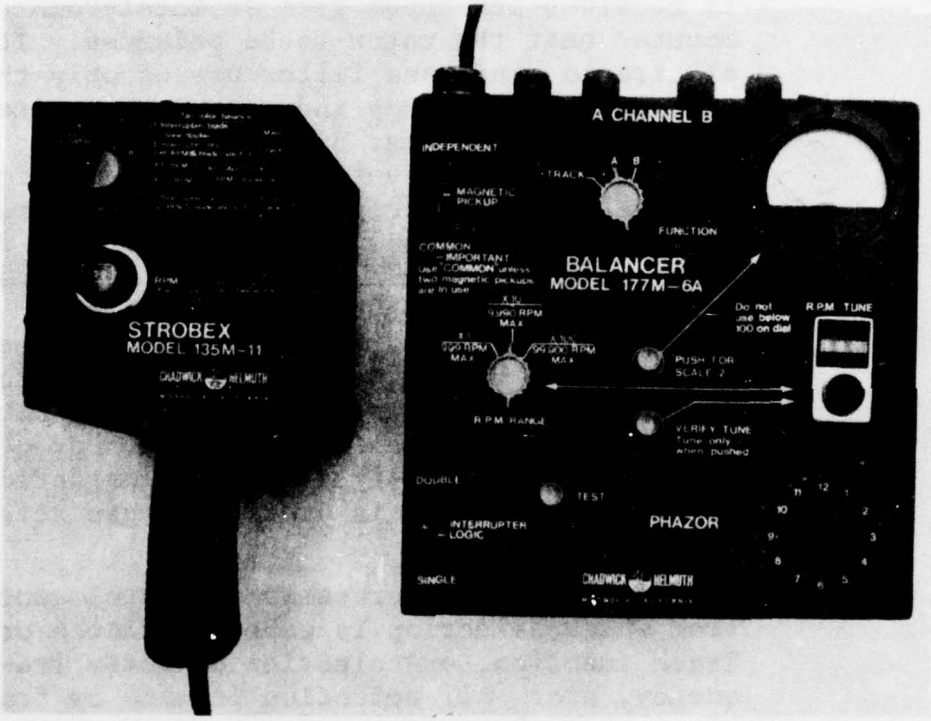


Figure 20-67. Chadwick-Helmuth's Balancer and Blade Tracker.

Description: The Strobex Blade Tracker is used for observing main rotor Track and Lead-Lag using Magnetic Pickup signal for triggering and for viewing characteristic phase angle of imbalance as sensed by Accelerometer and "processed" by Balancer.

The oscillator of the Strobex 135M-10A allows user to adjust flash rate to suitable multiple of tail rotor rate so that tip targets are superimposed for checking tail rotor

track. (No more stick in the tail rotor!) "Beep" adjustment positions targets for optimum viewing. Oscillator is also useful for viewing, in slow-motion, other rotating components.

The Balancer, Model 177M-6, uses information from rotor-induced vibration, to indicate amount and location of weights required to balance the rotor and eliminate the vibration. It receives its input from an accelerometer mounted near the rotor to be balanced. Its electronic band-pass filter passes only the one-per-rev frequency induced by that rotor and rejects all other disturbances. Its meter reads the amount of vibration, indicating the amount of weight required to correct it. Location of the required weights is determined by viewing the "clock angle" of a reflective target on the rotor, using the Strobex triggered by the Balancer. In the case of main rotors, the Phazor is used for determination of this clock angle in which case the Balancer delivers both the "processed" accelerometer signal and the Magnetic Pickup signal which is used for phase reference.

The Balancer also serves as a control center from which selection is made of Balance or Track function, or selection of rotor frequency, etc. All selection is made by front panel control.

The Phazor is used, in place of the Strobex, to determine the characteristic phase angle of imbalance of main rotors. The Magnetic Pickup signal is used as a reference against which the phase of the Accelerometer signal is measured. Clock angle is read from the lighted one of the 24 lights in the "clock face".

It is the quick, accurate and convenient way to read the required phase angle -- to determine location of weight -- on the main rotor, and it must be used on those ships whose main rotors are balanced in hover.

Balance Charts are used to convert the data from the Balancer - Strobex - Phazor instruments to the exact amount and location of a pair of weights required to accomplish balance.

The helicopter manufacturer generally provides for balance weight addition of specific points of his rotor system, and by various means (washers, different length screws, lead balls, "sweep" of blades, etc.). Usually it is found that the light side of the disc (where weight should be added) is at a point in space where there is no means of attachment.

Thus weight must be added at a pair of "authorized" points to yield the required result. The available points are often at different radii so the effect of weights in unequal, and they are generally not at 90° to each other, so that a chordwise correction affects spanwise balance, and vice versa.

The balance charts "reflect" the complex geometry of the weight attachment points and the "characteristic" angle of the location of imbalance for that type of ship, completely solving the difficult math problems posed.

The weight (in grams) to be added or subtracted at a specific pair of points is read directly from the chart.

20-2.9.5 Real Time Vibration Analyzers

Name:	On-Line Real Time Signature Analyzer
Manufacturer:	IRD Mechanalysis, Incorporated, 6150 Huntley Road, Columbus, Ohio 43229/(614) 885-5376
Model:	850/860 Figure No.: 20-68
Size:	9.1 in. H x 17.5 in. W x 20.5 in. D Weight: 850 - 53 lbs. 860 - 54 lbs.
Power Requirements:	115 VAC, 50/60 Hz.
National Stock No.:	- -

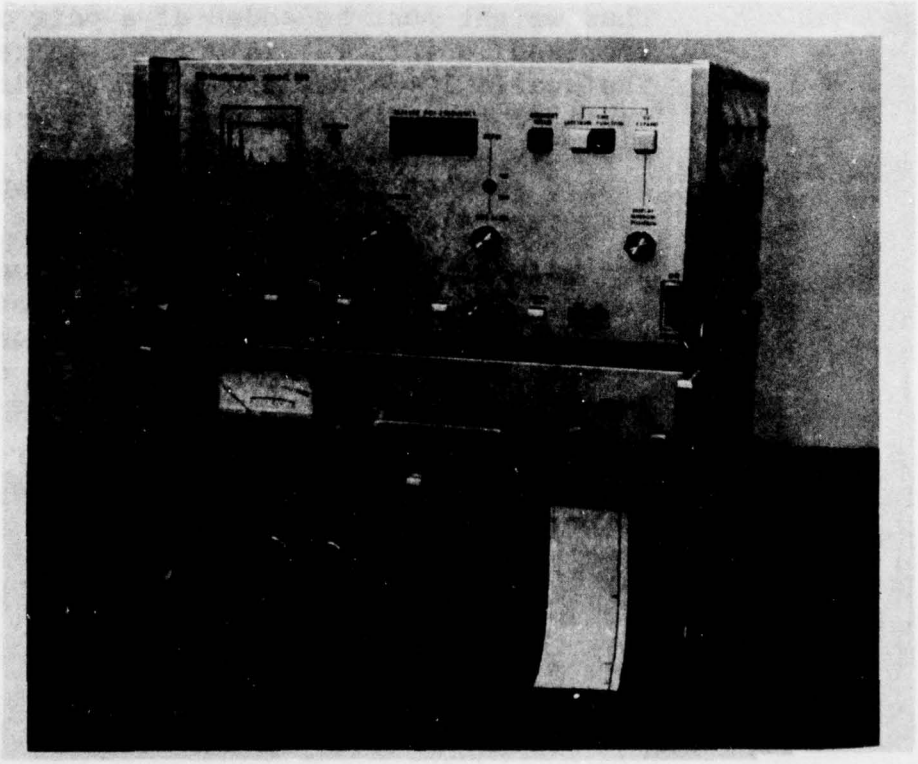


Figure 20-68. IRD Mechanalysis' Signature Analyzer.

Description: The portable Model 850/860 system provides on-line real-time analysis capability in a compact matched pair of units. All the needed accessories are built in: scope, hard-copy readout, averager and signal conditioning. The built-in completely automatic

recorder produces hard-copy XY plots in only four seconds; and plots can be produced singly, or continuously where changing machinery conditions exist.

The signal conditioner is designed to accept signals from most commercially available transducers; and, through sensitivity dials, direct readout of the signals is accomplished in useful engineering units (e.g., mils peak-to-peak). The signals can be analyzed and displayed as either vibration amplitude versus frequency, or vibration amplitude versus time. These vibration versus time signals can be stored in memory "HOLD" mode which is invaluable for all types of transient analysis including: shaft criticals, onset of oil whirl, other rotor instabilities and various impact type vibrations. A vibration signal stored in memory can be analyzed and displayed in six different ways without requiring additional data for optimum data presentation from a single sample.

Analysis of transient vibration is handled by front panel controls. Operator can select the sample length and vibration amplitude at which the analyzer will be triggered to store the data for analysis.

Accuracy of frequency identification and speed of analysis are accomplished with a movable dot marker displayed on the scope face, to identify the precise individual frequencies. When the dot marker is aligned with a frequency peak, the amplitude and frequency of that peak are simultaneously shown on large digital displays.

In-place balancing capability is provided by inputing a tachometer signal from the machine, in addition to the vibration signal. The scope display of these two superimposed signals provides phase and amplitude information when the primary cause of vibration is unbalanced.

Unsteady vibration signals, difficult to interpret, can be handled by the built-in averager. The averager effectively reduces random fluctuations so that amplitudes and frequencies can be more accurately measured. The averager has

two memories - averaged signals can be stored and later compared with the unaveraged and other signals.

The Signature Analyzer offers the following input signal specifications:

Frequency Range:	12 to 1,000,000 CPM in 8 ranges (0.2 Hz to 16.7 kHz).
Input Amplitude Range:	380 mV F.S. to 15V rms F.S. Front panel adjustable 100 K ohms approximately.

Name:	Mini-Ubiquitous Real-Time Frequency Analyzer
Manufacturer:	Nicolet Scientific Corporation, 245 Livingston Street, Northwale, New Jersey 07647/ (201) 767-7100
Model:	440A Figure No.: 20-69
Size:	12.9 in. H x 10 in. W x 20.5 in. D Weight: 42 lbs.
Power Requirements:	115 or 230 VAC, 49-63 Hz
National Stock No.:	- -

Figure 20-69. NSC's Portable Real-Time Frequency Analyzer.

Description: Model 440A is a real-time spectrum analyzer, designed to display the frequency components of a signal on-line. Each of the analyzer's 10 analysis ranges from 0-20 Hz to 0-20,000 Hz contains 400 resolution elements. This high resolution allows easy recognition of

closely-spaced frequencies, and reduces the chance of one frequency peak merging into the other.

Compared to a time signal, the frequency spectrum of noise or vibration provides a much easier way of identifying and separating the contributions of various signal sources ... gears, bearings, rotor blades. As test conditions change, the resulting signal spectrum likewise changes. The effects of varying test conditions ... motor start-up, pass-by noise, generator speed ... can easily be followed on line.

For signals which vary rapidly in a random or noise-like manner ... jet exhaust, fluid flow in a pipe, air turbulence ... a built-in averager "smooths" the amplitudes at each frequency. Where the instantaneous spectrum varies widely from moment to moment, the averaged spectrum varies much less. This means that averaged spectra taken at different times from the same signal will be similar. Repeatability is necessary if valid conclusions concerning the signal source are to be drawn from its spectrum or averaged spectrum.

Because the Model 440A Analyzer stores the input time function and allows the operator to view and plot it (before it is converted to a frequency spectrum) the instrument can also be used as a transient recorder. Single bursts of data ... punch press "band", electrical arcs, loose parts rattle ... can be captured and held digitally for recording and then spectrum analysis.

Because the analyzer reads frequency in cycles per minute (CPM), as well as cycles per second (Hz), direct readout in terms of RPM is possible. On the CRT, both the range and frequency at the cursor appear in units of CPM, if CPM reading is selected.

The Model 440 analyzer can also be purchased with a built-in translator (expansion plug-in) allowing magnification as much as 400:1 in any narrow region of the spectrum with resolution

as fine as 0.125 Hz. Input and analysis characteristics are:

Input Amplitude: Peak-to-peak voltage ranges are 100 mv (0 dB), 316 mv (10 dB), 1 V (20 dB), 3.2 V (30 dB), and 10 V (40 dB); FINE adjustment with 1-dB step vernier from 0 to 10 dB additional attenuation.

Input Sampling Rate: Set at 2.56 times maximum frequency of range selected on internal sampling (FREQ); external sampling input (ORDERS) sets frequency coverage of 1/2.56 of sampling rate (for normalizing spectrum to rotating device to display orders of rotation regardless of speed).

Frequency Ranges: 0-20, 0-50, 0-100, 0-200, 0-500, 0-1000, 0-2000, 0-5000, 0-10,000 and 0-20,000 Hz.

Number of Resolution Elements: 400 per spectrum (generated from 1024 input time samples).

Name: Vibrascope with VMAC (Vibration Monitor/ Analyzer Control)

Manufacturer: Spectral Dynamics Corporation, P.O. Box 671, San Diego, California 92112/(714) 565-8211

Model: 13180/13185 (VMAC) Figure No.: 20-70

Size: 8.8 in. H x 19 in. W x 20 in. D (Scope)
5 in. H x 19 in. W x 17 in. D (VMAC)

Weight: 48 lbs. (Scope)
25 lbs. (VMAC)

Power Requirements: 115/230 VAC, 50-400 Hz.

National Stock No.:

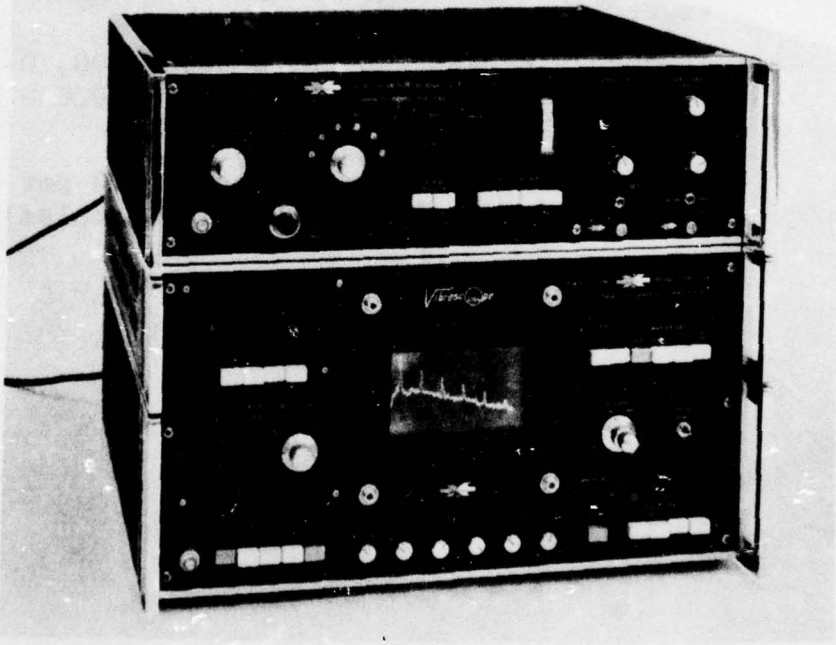


Figure 20-70. SDC's Vibrascope With VMAC

Description: The Vibrascope, a specialized Real Time spectrum analyzer, and the VMAC (Vibration Monitor/Analyzer Control) operate together as a system. They provide all the accuracy of laboratory instruments plus the operational simplicity needed in the plant or field for high-rate industrial quality assurance testing and machinery diagnosis. The Vibrascope/VMAC combination offers ...

Digital readout of overall vibration level from up to six channels of incoming data (accelerometers and velocity or displacement pickups).

Continuous display on a built-in scope of the vibration versus frequency spectrum in Real Time, permitting immediate identification of cause and effect in machine performance.

Digital readout of vibration amplitude in mils (peak-to-peak), inches per second (peak) and g's (peak).

Digital readout of speed or frequency and harmonic orders (as ratios of fundamental machine speed).

"SIMULPLOT" for simultaneous viewing of spectrum on oscilloscope and recording on X-Y plotter.

The Vibrascope has a frequency range of 0.6 Hz to 20,000 Hz in eight selectable ranges with a sensitivity of 1.0 Vrms full scale. The VMAC Unit has the following display modes:

Accelerometer - Acceleration: g's peak
Velocity: inches/sec, peak
Displacement: mils, peak-to-peak

Velocity Pick-Up - Velocity: inches/sec, peak

Displacement: mils, peak-to-peak

20-2.10 MISCELLANEOUS MEASURING SYSTEMS

Name:	Liquid Quantity System Test Set
Manufacturer:	Consolidated Airborne Systems, Inc., 895 Waverly Avenue, Holtsville, N. Y. 11742/ (516)654-3200
Model:	TF-20 Figure No.: 20-71
Size:	16.5 in L x 9 in H x 14 in W Weight: 30 lbs.
Power Requirements:	115 VAC, 400 Hertz, Single Phase, 25 Watts
National Stock No.:	4920-00-962-3097

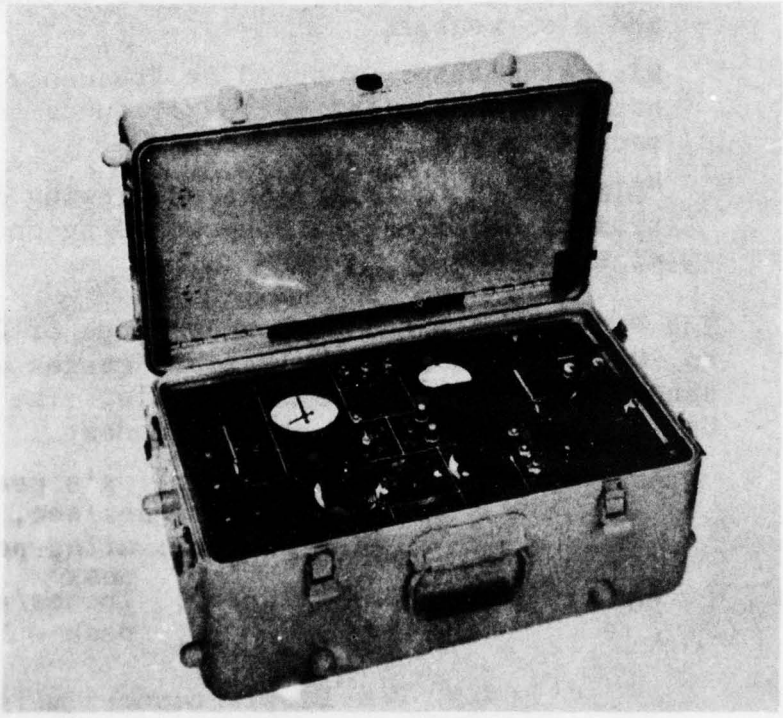


Figure 20-71. Consolidated Airborne Systems' Liquid Quantity Test Set.

Description: The TF-20 Test Set is designed specifically to provide the capability to test and calibrate capacitance type fuel gauge instruments, measure dc resistance and ac capacitance of fuel tank main and compensator probes, and check complete gauging systems installed in aircraft. Accessory cable and lead assemblies are provided as part of the test set to permit

AD-A040 129 RCA GOVERNMENT SYSTEMS DIV BURLINGTON MASS AUTOMATED--ETC F/G 15/5
TEST ACCESSIBILITY DESIGN GUIDE FOR ARMY MECHANICAL, HYDRAULIC --ETC(U)
SEP 76 F W HOHN, K G HOPKINS, R C BLANCHARD DAAA25-75-C-0681
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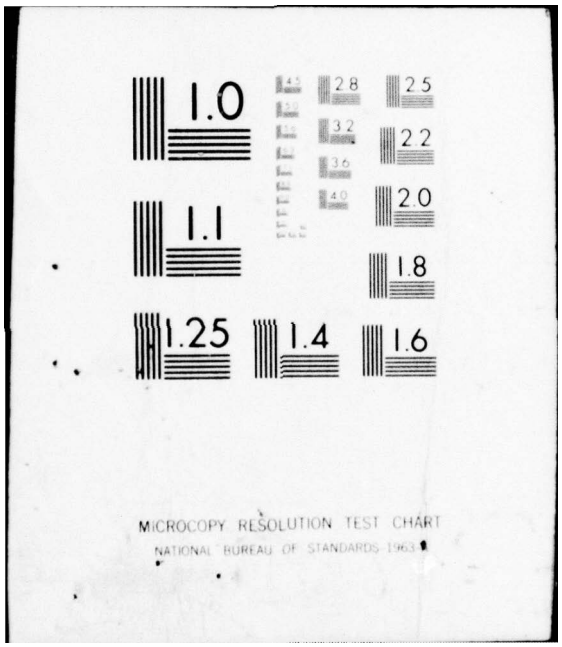
1.0
1.1
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1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963

interconnection with various type aircraft wiring harness installations, and also to bench test capacitance type fuel gauge instruments removed from the aircraft. The test set includes three basic types of circuitry: (1) a capacitance circuit to provide direct-reading values of capacitance from zero to 5000 UUF, in four ranges, (2) a megohm-meter circuit to provide direct-reading values of insulation resistance from zero to 10,000 M ohms, in four ranges, and (3) capacitance simulator circuits to simulate three capacitance-type fuel tank probes. The TF-20 and militarized model TD-20-1 Test Set is used where a capacitance-type liquid quantity gauge is to be calibrated and three simulated capacitances are required.

REFERENCES

1. DA PAM 700-21, The Army Test, Measurement, and Diagnostic Equipment Register Index and Instructions, Headquarters, Department of the Army, June 1976.

2. USAAMRDL-TR-74-44, Investigation of Inspection Aids, R.L. Cahoon, F.W. Hohn, et al., prepared for Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, For Eustis, Virginia, 23604, July 1974.

CHAPTER 21
SURVEY OF AUTOMATIC TEST SYSTEMS

21-1 INTRODUCTION

Automatic test systems are relatively new to the Army as well as to many commercial enterprises. As the quantity of equipment and the complexity of equipment increases, automatic test equipment becomes an economic and practical necessity. Realization of these needs is increasing; the goal of increased operational readiness for equipment, vehicles and aircraft is now recognized as highly desirable in DoD planning. This chapter presents an overview of automatic test and monitoring systems that exist today for mechanical, hydraulic and pneumatic material.

Automatic test and monitoring systems are defined as systems which are computer or controller/processor controlled. They are programmable, at least in design, and usually employ feedback to the operator. As such, they all have decision making capability, may employ operator intervention in making decisions, and measure or monitor a number of parameters. A sampling of military and commercial systems follows in a format presenting manufacturer information, a system photograph and a brief description of its design features and capability.

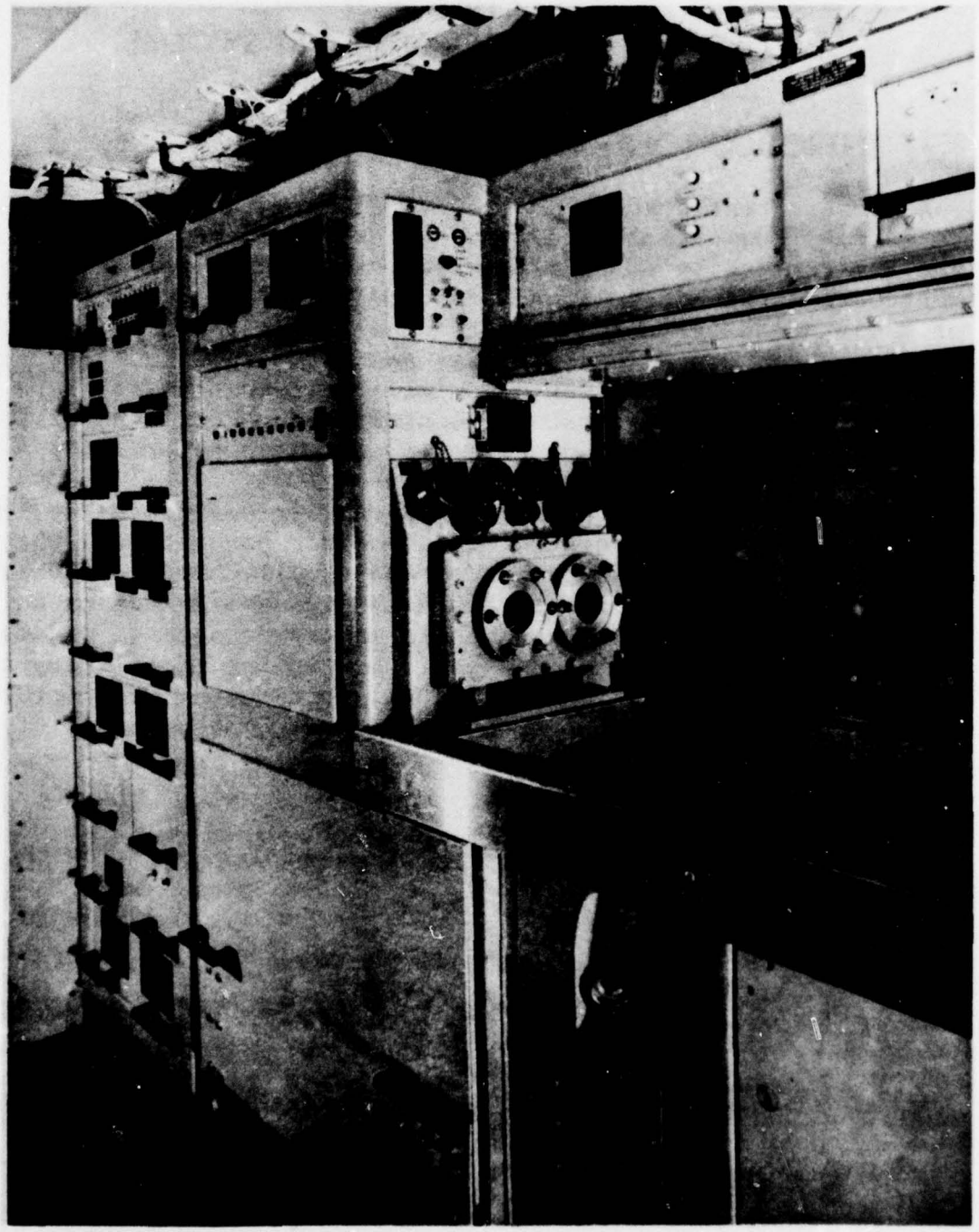

Figure 21-1. Hydraulic Test System, Shelter Mounted

21-1.1 Hydraulic Pneumatic Computer Operated Test Stand (HPTS)

Manufacturer: RCA, Automated Systems Division, P.O. Box 588, Burlington, Massachusetts 01803 / (617) 272-4000

Subcontractor: Greer Hydraulics, Inc., 5930 West Jefferson Boulevard, Los Angeles, California 90016 / (213) 870-9161

Model: HPTS Figure No.: 21-1

Size: 72in L x 66in H x 22in D Weight:

Power Requirements:

National Stock No.:

Description: The HPTS is an example of an early development of an automated hydraulic-pneumatic test stand. It was built for Army mobile field support for missile systems in the early 1960's. The test stand is completely computer-controller run. Not only are hydraulic component tests performed completely automatically, but the test results are also evaluated by the computer. An extension of the concept permits the computer to make logical decisions in the event of component malfunction, for failure to meet a test criterion, and to inform the operator of the probable nature of the fault and the corrective action necessary.

This machine will test all hydraulic components whether rotating or non-rotating. It is also capable of testing air compressors and missile pneumatic components. One of the more striking tests performed by this machine is fully automatic testing and evaluation of servo valves, both hydraulic and hot gas.

Inherent in the HPTS design is the capability to test a major portion of missile hydraulic components in current usage, as well as those in development. It is capable of testing the following types of units:

(1) Linear actuators
(2) Rotary actuators
(3) Hydraulic pumps (and systems)
(4) Servo valves (and systems)

(5) Hydraulic motors
(6) Relief valves
(7) Flow regulators
(8) Accumulators
(9) Solenoid valves
(10) Pressure transducers
(11) Manual selector valves
(12) Pressure regulators
(13) Pneumatic hot gas servos
(14) Hydraulic subsystems
(15) Check valves

The HPTS can be utilized to perform field and depot level maintenance on components and is limited only by input power. However, higher power pumps and motors may still be tested, first at maximum pressure and then at maximum flow. The HPTS provides:

(1) Capability for test and repair of hydraulic and pneumatic components of missile and similar weapon systems
(2) Capability for either internal or external testing
(3) Remote control by other units, when computer capability is required
(4) Limited pneumatic capability (as described in Table 21-1)
(5) Assembly and spares interchangeability with other Army test equipments
(6) Self-contained repair station.

Operator participation is required to the extent of making test unit adjustment and alignment or, in some instances, re-arrangement of hydraulic stimulus and measurement points at the test unit.

TABLE 21-1. HYDRAULIC-PNEUMATIC STIMULUS

Pressure range	250 to 5,000 lbf/in^2
Flow range	2 to 20 gal/min (to 3,000 lbf/in^2) 2 to 11.5 gal/min (to 5,000 lbf/in^2)
Leakage detection	1 to 500 cm^3/min
Hydraulic fluid temperature	160°F maximum (Provisions for 250° operation)
Mechanical drive	30 hp delivered to shaft
Low speed shaft	100-4,000 rev/min
Speed increaser	200-8,000 rev/min
High speed shaft	150-6,000 rev/min
Speed increaser	300-1,200 rev/min
Torque measurement	Up to 1,000 in·lbf
Filtration	
Super clean loop	3 μm nominal
Operating loop	5 μm nominal
Pneumatic	1,500 lbf/in^2 air, 19 ft^3/min, for 15 minutes (5,000 lbf/in^2 source)

21-1.2 Hydraulic Test Facility (HTS)

Manufacturer: RCA, Automated Systems Division, P.O. Box 588, Burlington, Massachusetts 01803 / (617) 272-4000

Subcontractor: Cox Instrument, 15300 Fullerton Avenue, Detroit, Michigan 48227 / (313) 838-5780

Model: HTS Figure No.: 21-2

Size:

Power Requirements:

National Stock No.:

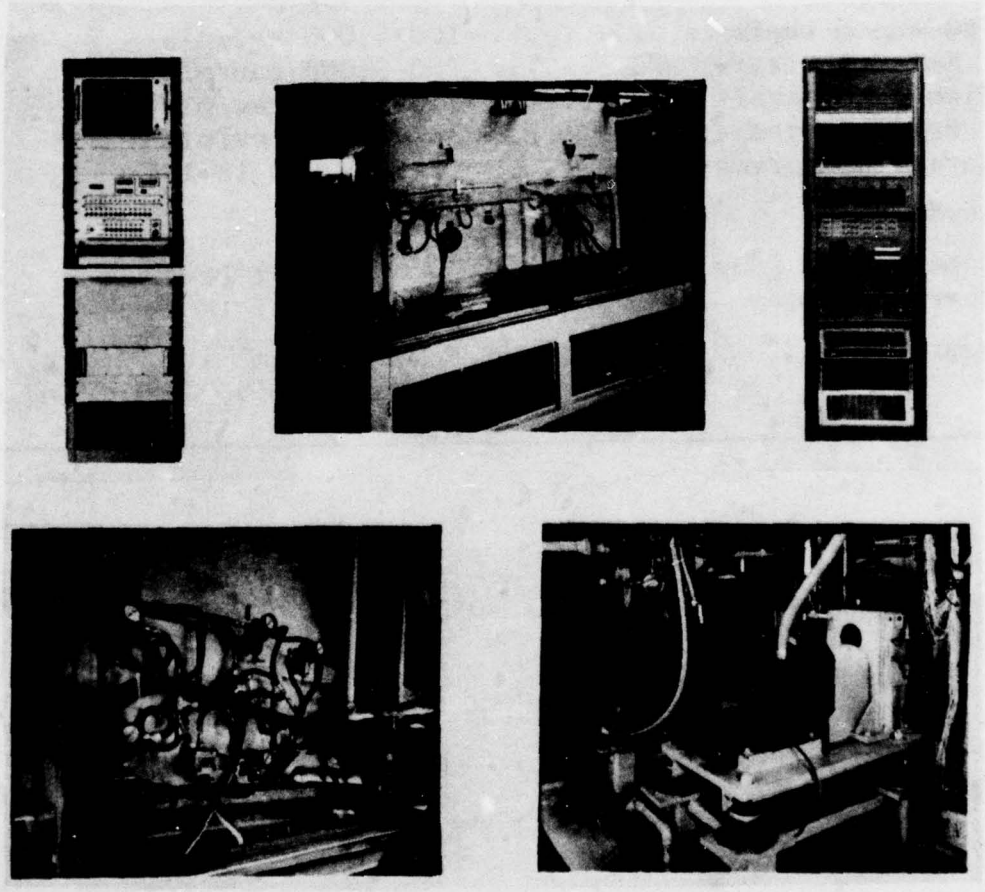

Figure 21-2. RCA's HTS Hydraulic Test Facility

Description: Aircraft hydraulic systems use three basic configurations of hydraulic pumps and motors. HTS is a multi-stand test facility which automatically tests these three types of aircraft pumps and motors. The hydraulic test facility consists of ten test stands, a central hydraulics complex, an enclosure acoustically separating test stand faces from all rotating machinery, and a central computer enclosure. There are six pump test stands, two starter test stands, and two pump/motor test stands. Tables 21-2 through 21-4 identify the respective stands capabilities.

The starter for which the starter test stands are designed are high-speed hydraulic motors. They generate substantial shaft horsepower that is absorbed regeneratively by returning electrical power to the main bus, either in their speed/braking mode or in their selectable inertia-simulation mode.

TABLE 21-2. RATINGS OF PUMP TEST STANDS

Function	Range
Variable speed reversible drive pad:	
Shaft power	25 to 200 hp
Speed	7,500 to 10,000 r/min
Low-pressure oil supply	15 to 90 gal/min @ 120 lbf/in^2
Re-circulating oil temperature	120 to 300°F
Back-pressure control	200 to 5,000 lbf/in^2
Drain service connection	5 to 15 gal/min

TABLE 21-3. RATINGS OF STARTER TEST STANDS

Function	Range
Variable speed reversible regenerative (braking) drive:	
Shaft power	50 and 150 hp
Low-speed pad	15,000 r/min
Over-speed pad	30,000 r/min
High-pressure oil supply:	
Oil pressure	100 to 5,000 lbf/in^2
Oil temperature	120 to 300°F
Oil flow rate	20 to 50 gal/min
Simulated inertia mode:	
Maximum inertia ratings	4 and 8 $slug-ft^2$

TABLE 21-4. RATINGS OF PUMP/MOTOR TEST STANDS

Function	Range
Variable speed reversible drive pad:	
Shaft power	50 and 100 hp
Speed	15,000 r/min
Hydraulic supplies:	
Low pressure (120 lbf/in^2 maximum)	40 and 60 gal/min
High pressure (to 5,000 lbf/in^2 maximum)	40 and 60 gal/min
Oil temperature	120 to 300°F

The simulated inertia mode utilizes a torque-control circuit commanded by an electrically differentiated tachometer signal. Thus, it is possible, by simply varying the gain of this angular acceleration signal, to simulate inertia values from near zero to the values listed above and even higher.

Fluid temperature control is achieved in these stands by the appropriate mixing of two sources of 5,000-lb/in^2 oil, one at

120°F, the other at 300°F. This permits fluid at various temperatures to be supplied simultaneously at all four motor-type stands.

The two pump/motor test stands are the most complex of the ten, combining most of the components and circuits used in the pump and starter stands. Consequently the variable speed drives are capable of delivering shaft horsepower to the component being tested when operating in the motor mode. They do not, however, contain an inertia mode.

Two kinds of fluid temperature control are used: recirculation for pump operation and fluid mixing of high-pressure sources for motor operation.

The central hydraulics configuration includes a low-pressure manifold. The 15-hp boost pumps provide both the 120-lb/in^2 oil to the six pump stands and the boost pressure to the low temperature, high-pressure pumps. The high-pressure supply comprises one variable and two fixed displacement pumps that together provide low temperature fluid according to the flow demands.

In the high-temperature, high-pressure circuit, two fixed displacement pumps are provided in a recirculating loop using a steam heat exchanger to achieve the 300°F temperature required.

A central oil-to-water heat exchanger is also located immediately in front of the reservoir.

Finally, HTS includes an on-line particulate monitoring system. The on-line monitoring system is able to alert the operator to a malfunctioning pump by indicating an abnormal rise in the count early in the run-in period.

21-1.3 Automatic Test System for Jet Engine Accessories (ATSJEA)

Manufacturer: RCA, Automated Systems Division, P.O. Box 588, Burlington, Mass chusetts 01803 / (617) 272-4000

Subcontractor: Cox Instrument, 15300 Fullerton Avenue, Detroit, Michigan 48227 / (313) 838-5780

Model: ATSJEA Figure No.: 21-3

Size: Weight:

Power Requirements:

National Stock No.:

Description: The ATSJEA provides a fully automated test facility for a wide range of jet aircraft fuel controls, pumps, and similar accessories. Computer-directed programs control, measure, record, sequence, and evaluate individual tests. In ATSJEA, RCA has applied highly advanced automatic test concepts to a non-electronic test environment, in which hydraulic and pneumatic flows and pressures, mechanical rotations, and physical linkages, are the principal elements to be exercised. Automation provides accuracy, repeatability, and reliability in testing not normally realized in manual systems, plus a four-fold increase in testing speed.

The ATSJEA system was designed to provide automatic testing of jet engine accessories such as fuel controls, fuel pumps, spray nozzles, constant speed drives, hydraulic pumps, hydraulic pump/motors, and hydraulic motor starters.

Figure 21-3 illustrates the total system. At the top of the figure is the central processing system (items 1-9, 15) consisting of a main frame, a console teletype two random access discs, the digital input output (DIO), a card reader, card punch and line printer. The computer, teletype, and discs perform the automatic mode test control. The card reader, card punch, and line printer serve principally for program generation facilities. The lower left part of Figure 21-3 contains the electrical power cabinet

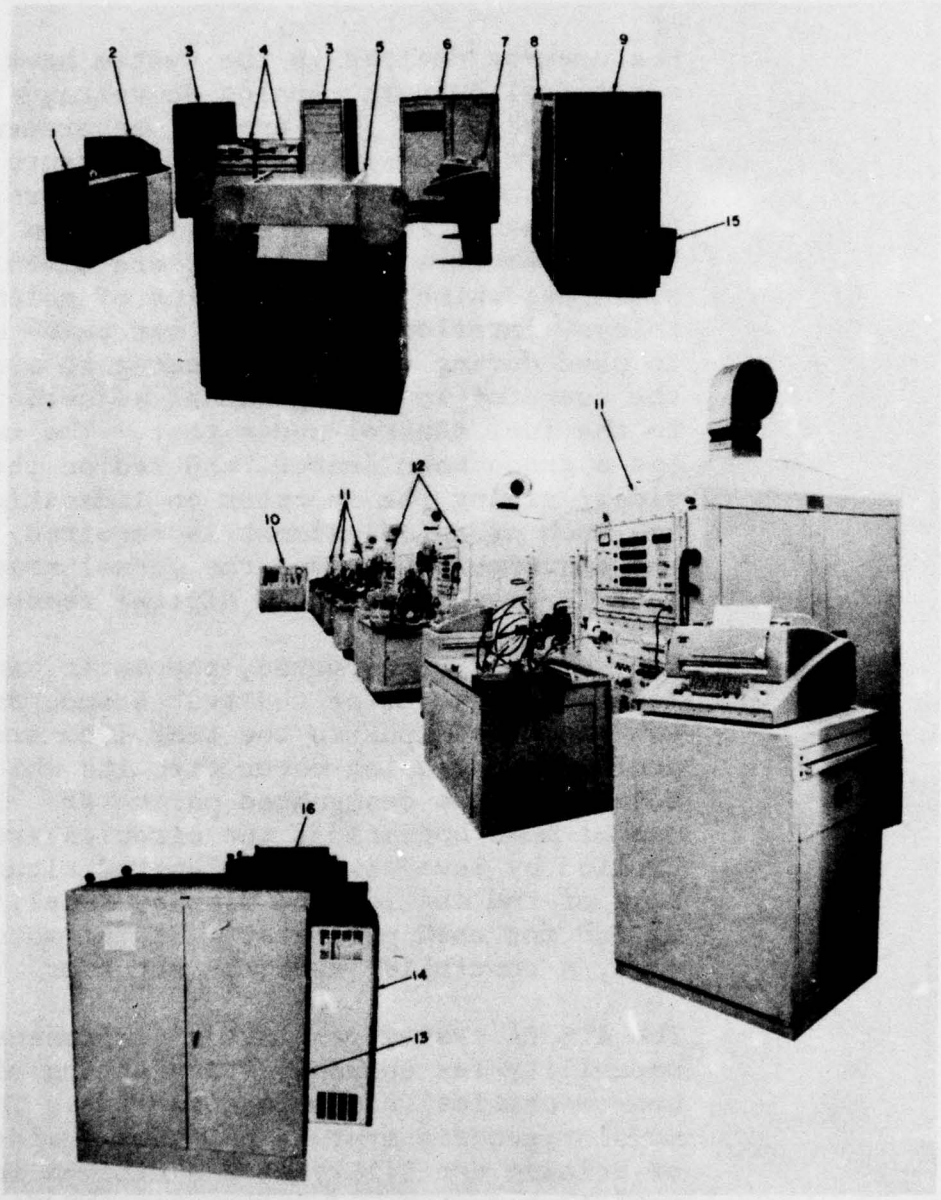

Figure 21-3. RCA's ATSJEA System

assembly, variable speed control, and power distribution. Item 10 in the figure is the calibration cart assembly; item 11 the fuel control test stand assembly; and item 12, the high flow test stand assembly.

Measurement devices in the system have electrical outputs, analog dc voltages, and digital signals. The analog measurements are derived from strain gauge pressure transducers, thermocouples, potentiomenters, etc. Digital measurements are derived from turbine flowmeters, tachometer, and circuit closures, which include status of solenoids, relays, interlocks, etc. A set value meter is used during automatic testing to assist the operator in making manual adjustments to the fuel control under test. The meter has a green band center, and red on the sides, giving the operator an indication of how much of an adjustment is required. Once the adjustment is made, the actual measurement is displayed on the digital readout.

Control of the hydraulic, pneumatic, and mechanical status of the test stand, and the stimulus input to the test item are controlled by stepping motor circuits which adjust/set the designated parameter. In manual mode operation, the circuits are controlled by lever switches located along the base of the control and display panel, one switch for each parameter. In the automatic mode, a controller sets the actuator.

The ATSJEA system provides a comprehensive capability for the automatic testing of hydromechanical engine accessories. The modular/generic feature provides a wide range of testing capability with a minimum investment in hardware and software. ATSJEA has direct application to fuel controls, fuel system components, hydraulic components, and constant speed drives.

21-1.4 Air Modular Engine Test System (METS)

Manufacturer: Avco Lycoming Division, 550 South Main Street, Stratford, Connecticut 06497 / (203) 378-8211

Model: Air METS

Figure No.: 21-4

Size: 260in L x 109in H x 100in W

Weight: 17,000lbs

Power Requirements: Self-contained

National Stock No.:

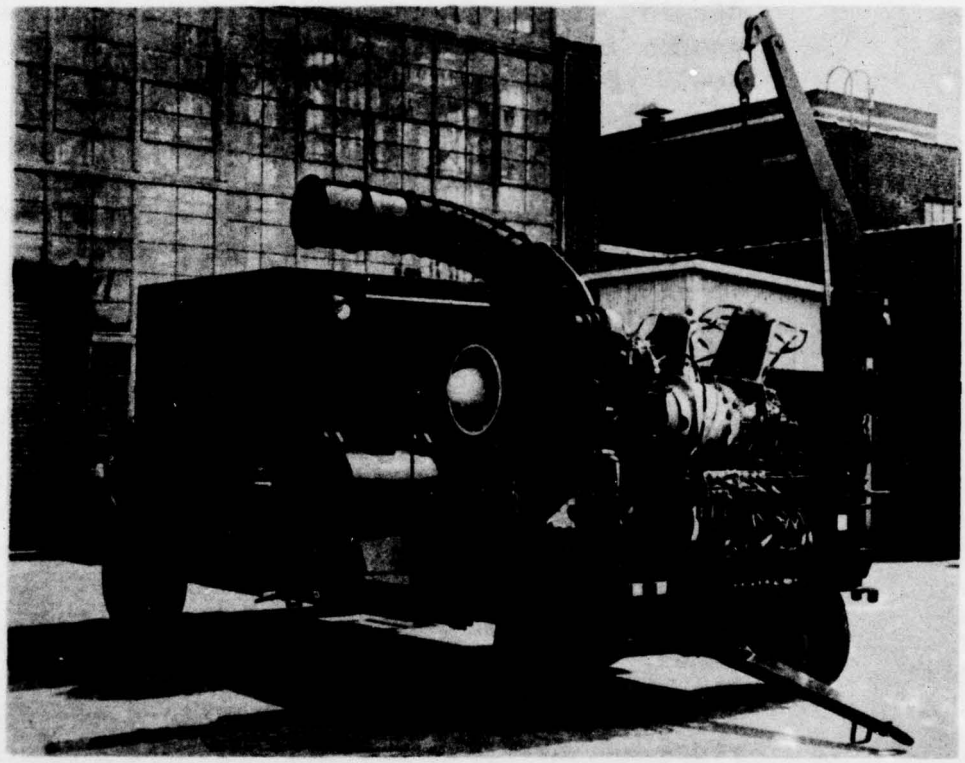

Figure 21-4. Avco's Air Modular Engine Test System

Description: The mobile air METS utilizes an air dynamometer as the power absorption device. The test trailer module consists essentially of a frame and the running gear, control cab, oil and fuel system, electric power unit, engine starting system, hoist assembly, data acquisition assembly, engine test dolly and air dynamometer. This system will test all

shaft turbines up to 2,200 hp at 6,000 rpm with a single air dynamometer. For speeds up to 20,000 rpm, a different air dynamometer is employed and for power plants up to 5,000 hp, a third dynamometer is used.

Instrumentation in the control cab includes a console functioning as the complete data display and engine control center. The data display system features digital readouts with random access to all engine parameters during test. Engine control is achieved by the use of hydraulic power lever actuators. The instrumentation is set up in modular panels with groupings established to monitor all essential engine functions, as well as the test support equipment and operational systems.

In operation of the METS system, engines to be tested are moved to the module on a four-wheel dolly. This dolly allows the engine to be mounted and dressed in a convenient area prior to being moved to, and hoisted up to, testing position on the trailer. During set-up, interface plates are mounted on the side of the dolly to act as a sequencer for the engine dress cables and hoses of the quick-coupling type. The data acquisition assembly is positioned on four vibration mounts at the front of the trailer. It provides an interface between the test engine and the control cab instrumentation.

The air dynamometer used in the air METS mobile test facility is of a centrifugal compressor design, capable of applying a load up to 2,000 hp. A torque system, incorporated in the air dyno and secured to the test stand support, determines the amount of load or torque being applied to the engine and transmits the torque signal to the indicator. A quill shaft arrangement is used in coupling the test engine to the dynamometer, the output shaft of the engine mating with the air dynamometer input shaft.

Air METS is self-contained and fully capable of operating anywhere, regardless of existing facilities. By selecting the appropriate METS modules, engine maintenance can be performed at lower maintenance echelons on suspect or damaged engines, thereby eliminating engine transportation problems and reducing aircraft down time. Air METS may also be used to perform new or overhaul engine testing to return the engine to service.

21-1.5 TRENDS Engine Condition Monitoring System

Manufacturer: Hamilton Standard, Windsor Locks, Connecticut 06096 / (203) 623-1621

Model: TRENDS

Figure No.: 21-5

Size: 70in H x 24in W x 31in D

Weight: 600 lbs (Central Unit)

Power Requirements: 117VAC, 60Hz, Single Phase, 30 Amps

National Stock No.:

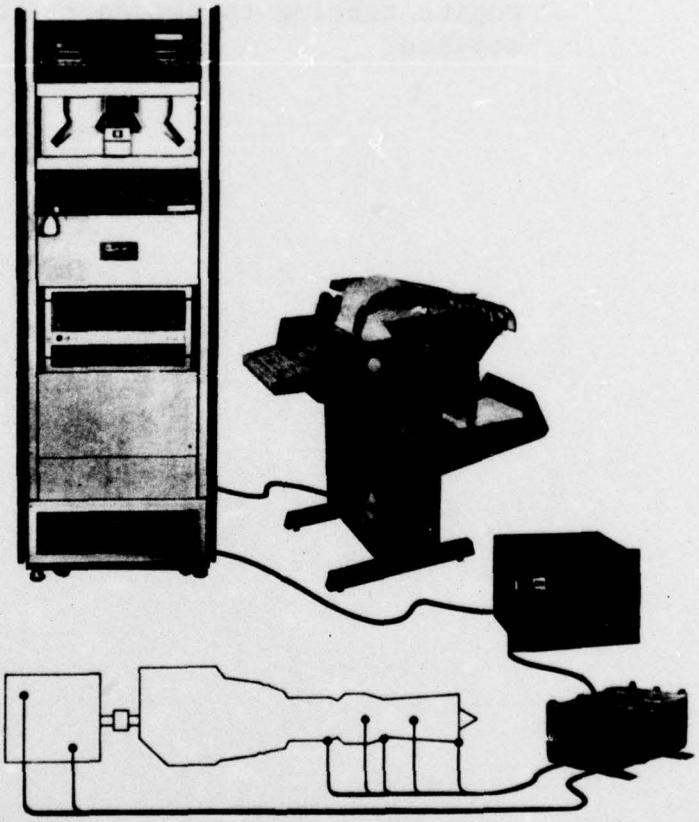

Figure 21-5. Hamilton Standard's TRENDS System

Description: The TRENDS system is designed to automatically monitor and report gas turbine engine and electrical generator operation in terms significant to station managers and operating

personnel. It is a utility oriented diagnostic and prognostic system named from the title TRend Analysis and ENgine Diagnostic System. Figure 21-5 is a pictorial grouping of major components of the TRENDS system. Clockwise from the top is the central unit, containing a processor and peripheral units; the print-keyboard providing for data I/O; a data collection unit, which may be located remotely from the central unit; and an engine transducer box interfacing sensors installed on the engine or generator shown in outline.

Objectives of the TRENDS system are to facilitate maintenance action by:

- Insuring the earliest possible note of detectable engine performance changes
- Performing accurate multiple-fault diagnoses and prognoses of engine problems
- Monitoring electric generator condition
- Performing mechanical analysis of accessory systems such as lube oil systems
- Detecting incipient degradations and predicting when failures are likely to occur through trending and regression analysis
- Issuing plain language maintenance instructions to correct detected problems

The system utilizes microprocessors to gather information from sensors and selectively communicate data to a central processor unit. The central unit analyzes and reports to the user information on the current system status, engine condition, related systems, and impending events predicted from data trends established in the engine history file. The central unit is a powerful processor operated to collect, analyze, save and report data collected from the engine network. The data collected from each engine in the system is subjected to a unique gas path analysis process that can reveal and isolate engine degradations that are a sure sign of impending trouble. Fuel utilization is examined to identify those engines

that are costing too much to operate in an untrimmed or degraded state. Engine utilization histories are maintained and reported without reliance on manual record-keeping. Engine status reports are available on a periodic or demand basis. Diagnostic and plain language maintenance instructions are printed out when events and engine condition so dictate.

Options are offered which permit additional diagnoses to be made on the lube oil, generator and fuel systems as well as more rigorous approaches to gas path analysis. The list of gas turbine engine parameters which can be measured follows:

Mass Flow Measurements	N_1
MWH Meter Interface	N_2
PT_2 Plenum Inlet Pressure	N_3
PS_4 Compressor Discharge Pressure	T_{T7}(1-6)EGT
PT_7 Gas Generator Exhaust Pressure	Oil Temperature - GG
	Oil Temperature - FT
Oil Breather Pressure - GG	GG Vibration, Cold End
Oil Breather Pressure - FT	GG Vibration, Hot End
Oil Filter Pressure Drop - GG	Expander Generator Vibration
Oil Filter Pressure Drop - FT	Anti-Icing Requirements - Sensed
P_3 Compressor Discharge Pressure	Anti-Icing Power (on/off)
T_3 Compressor Discharge Temperature	Anti-Icing Valve (open/closed)
T_I Compressor Inlet Temperature	Engine (on/off)
Lube Oil Level - GG	Power Select (min, base, peak; max peak)
Lube Oil Level - FT	
Fuel Temperature - Gas	Start Select
Fuel Flow - Liquid	Shutdown Select
Fuel Temperature - Liquid	Fuel Select (gas/liquid)

21-1.6 Automatic Inspection Diagnostic and Prognostic System

Manufacturer: Airesearch Manufacturing Co. of California, A Division of the Garrett Corporation, 2525 West 190th Street, Torrance, California 90509 / (213) 323-9500

Model: AIDAPS Figure No.: 21-6

Size: 22in W x 12.5in H x 20in D(DA) Weight: 105 lbs (DA)

Power Requirements: 115 VAC, 60/400 Hz

National Stock No.:

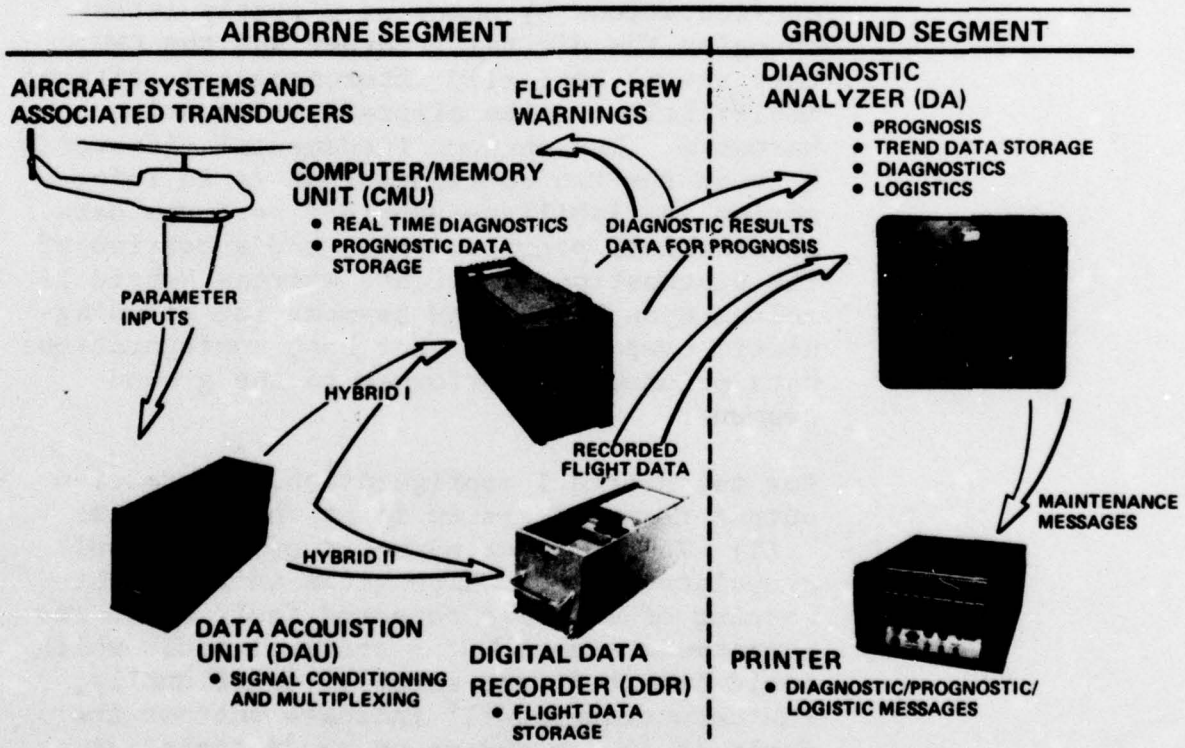

Figure 21-6. Garrett's AIDAPS Prototype System

Description: The AIDAPS consists of an airborne segment and a ground segment. The airborne segment consists of (1) transducers, (2) a data acquisition unit (DAU), (3) a cockpit

annuciator panel, and (4) a computer memory unit (CMU), or digital data recorders (DDR). The ground segment, shown in Figure 21-6 will consist of (1) a diagnostic analyzer (DA), and (2) a digital printer. The system can be used in either of two configurations: Hybrid I, which includes the CMU and incorporates on-board fault detection and diagnostics; or Hybrid II, which substitutes the digital recorder for the CMU and provides airborne data acquisition with ground processing. The system is modularly interchangeable between the Hybrid I and Hybrid II configurations by means of directly interchanging the digital recorder and the CMU; they are mechanically interchangeable without modification to the aircraft or mounting hardware. The obvious fundamental difference between the two configurations is in information availability—Hybrid I performs data acquisition, preprocessing, and a portion of the diagnostics in flight, whereas Hybrid II relies upon the ground segment for all diagnostic computations. For both configurations data printout is performed in the ground segment.

For the Hybrid I configuration, information output from the system is at three levels:

(1) To the pilot by means of the cockpit annuciator panel, which gives an in-flight warning of either a detected fault which requiresmaintenance, or a critical fault which could impact flight safety. Additionally, the annunciators will indicate whether the fault is in the engine or power train. A fourth annunciator indicates the necessity to transfer data from the CMU to the DA.

(2) To the pilot or maintenance crew by means of a 3-digit display on the front panel of the CMU. This display, which is accessible to the crew when the aircraft is on the ground, will allow them to determine more specific information about faults which are detected in flight by the CMU. It is intended to be used immediately after landing,

when a fault has been indicated by the cockpit annunciators, and provides a level of self sufficiency to the aircraft (i.e., some of the diagnostic results are available without processing at the DA). The message codes used for the CMU display correspond to messages which are printed out when data is processed at the DA. If more than one fault is detected by the CMU, they may be read out sequentially by pressing the "advantage" button. Additionally, three latching annunciator flags are located on the CMU front panel to indicate failures of AIDAPS components (sensors, DAU, or CMU) which are detected by the self test or diagnostic routines.

(3) To the ground crew by means of the DA and printer. The DA performs a portion of the diagnostics for Hybrid I. The results of processing is an output in the form of a hard copy printout. The CMU message codes and the DA messages are both printed. Additional messages will also appear via the printer as a result of DA processing.

For the Hybrid II configuration the transfer data light is lit in the cockpit when the recorder is out of tape. This calls for processing of the tape-recorded data at the DA. No other outputs are available on the aircraft. Information is given to the ground crew by means of the DA and printer. The DA performs all diagnostics and provides all of the functions which are accomplished by the CMU and the DA in a Hybrid I configuration except that they are performed on the ground. The printout format and information content is identical for both configurations.

An important feature of the system is the aircrafts independence from any ground station. The characterization data for each aircraft is stored on-board in the CMU core for Hybrid I, and on the digital data tape for Hybrid II. This characterization data consists of the serial numbers and elapsed

operating times for principal LRUs, the baseline data which characterizes the normal operating performance for these LRUs, and the trend history data accumulated for those LRUs. This allows any aircraft to operate in conjunction with any ground station. Each time that data from a CMU or a DDR is processed at the DA, the updated data is reloaded into the CMU or DDR.

In addition to processing flight data, the DA provides the capability to compute baseline functions for LRUs from flight data. Also, it provides a facility for entering LRU serial numbers, time-in-service, etc., when LRUs are initially installed or changed.

The AIDAPS system relies on twenty-eight input signals consisting of seventeen transducers and eleven existing signals (for the UH-1H aircraft) as follows:

Transducers	Existing Signals
1. Fuel Flow	1. N_1
2. Fuel Temperature	2. N_2
3. P_{S1}	3. EGT (7)
4. P_{S3}	4. Engine Oil Temperature
5. Torque Pressure	5. Engine Start SW.
6. T_{T3}	6. XMSN Oil Temperature
7. ΔP_S	7. XMSN Oil Pressure
8. IGV	8. XMSN Oil Pressure SW.
9. T_{T1}	9. Chip Det. (3)
10. Bleed Band Position	10. XMSN Oil Temperature SW.
11. Brg 2 Scav. Oil Temp.	11. Misc. Discretes
12. Brg 2 Scav. Oil Pr.	
13. XMSN 1 of ΔP	
14. XMSN X of ΔP	
15. Chip Dct. (3)	
16. Vibration (11-14)	
17. Aircraft Ident.	

All units are fully deployable to forward bases and are ruggedized for field use. Functions of the diagnostic analyzer include development of both thermodynamic and vibration baselines, trend analysis, and diagnosis and printout of LRU faults and required maintenance action.

21-1.7 Gas Turbine Engine Health Monitor

Manufacturer: General Electric Company, Aircraft Engine Group, 1000 Western Avenue, Lynn, Massachusetts 01910 / (617) 594-0100

Model: T-700 (prototype) Figure No.: 21-7

Size: Weight:

Power Requirements: 115 VAC, 400 Hz

National Stock No.:

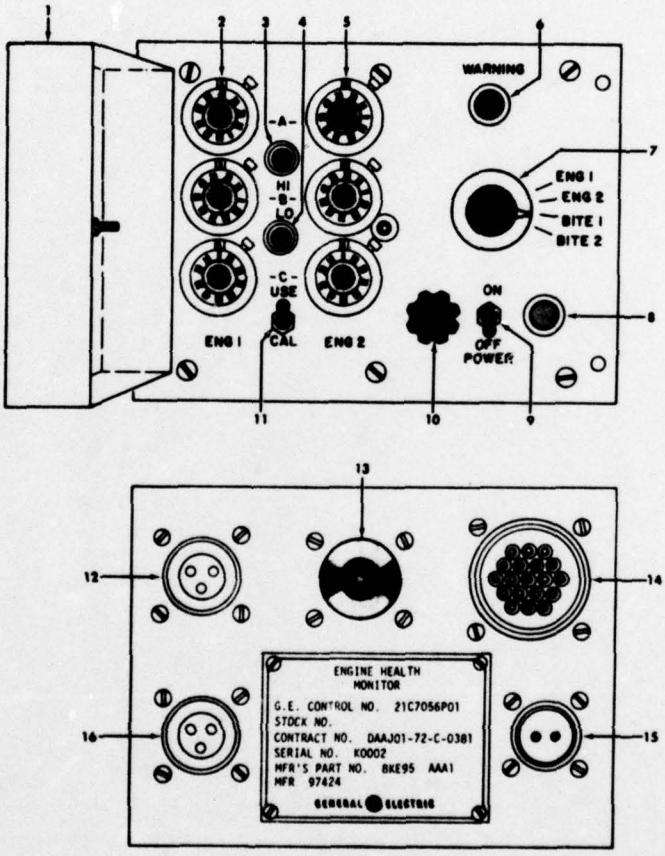

Figure 21-7. General Electric's T-700 Engine Health Monitor

Description: The engine health monitor (EHM) is an airborne analog electronic device which senses power turbine output torque, (normally, power turbine speed is governed at a constant

rpm. Therefore, output torque is directly proportional to output shaft horsepower) and PT inlet gas temperature signals and provides a warning indication when engine performance has deteriorated below a preset level. This is accomplished for a wide range of either new or overhauled engine performances by storing the engine performance curve into the device through three potentiometer adjustments. For any turbine inlet temperature signal input within the operating range, the characterization circuit generates a voltage equivalent to what the engine output torque should be if no deterioration has occurred. A preset percentage of this signal (representing the allowable deterioration) is compared with the actual input torque signal. A warning light will start to flash when within two percent of the allowable deterioration. The light will stay on continuously at, or beyond, the preset allowable deterioration limit.

An "RTD" temperature sensor and a pressure transducer are included to provide signals to the EHM for automatic altitude and outside air temperature corrections to the engine signals. The Health Monitor requires an initial calibration to insert the newly-installed performance characteristics of each engine. Subsequent use merely requires the activation of a switch while the engines are at any power level from approximately 50 percent to 100 percent, and when the aircraft is below 100 knots flight speed.

The EHM front panel (refer to Figure 21-7) contains one rotary switch, the warning signal light, a normally closed hinged cover, power switch, power-on lamp and fuse holder. Access to the characterization adjustment pots (three for each engine), CAL/USE switch and "Hi-Lo" lights (for indication of correct mid-point calibration setting) is gained by losening one screw in the hinged

cover. An absolute pressure transducer mounted inside the EHM and external RTD cable assembly are provided for automatic ambient pressure and temperature correction, respectively.

Identification of the external parts of the EHM are made numerically on Figure 21-7 as follows:

(1) Hinged cover
(2) Characterization potentiometers (engine 1)
(3) High locator lamp
(4) Low locator lamp
(5) Characterization potentiometers (engine 2)
(6) Warning lamp
(7) Selector switch
(8) Power lamp
(9) Power switch
(10) Fuse
(11) Calibration switch
(12) Resistance temperature detector (RTD) receptacle J1
(13) Barometric pressure port
(14) Input receptacle J4
(15) Power receptacle J3
(16) Remote warning lamp receptacle

Inputs to the EHM are torque, turbine inlet (temperature, ambient pressure, and ambient temperature). The algorithm used for characterizing T-700 engine thermodynamic output performance is corrected torque versus corrected power turbine inlet temperature. BITE circuitry is also included to test EHM operation.

21-1.8 Automatic Test Equipment/Internal Combustion Engines

Manufacturer: RCA, Automated Systems Division, P.O. Box 588, Burlington, Massachusetts 01803/(617) 272-4000

Model: ATE/ICE Figure No.: 21-8

Size: Weight:

Power Requirements:

National Stock No.:

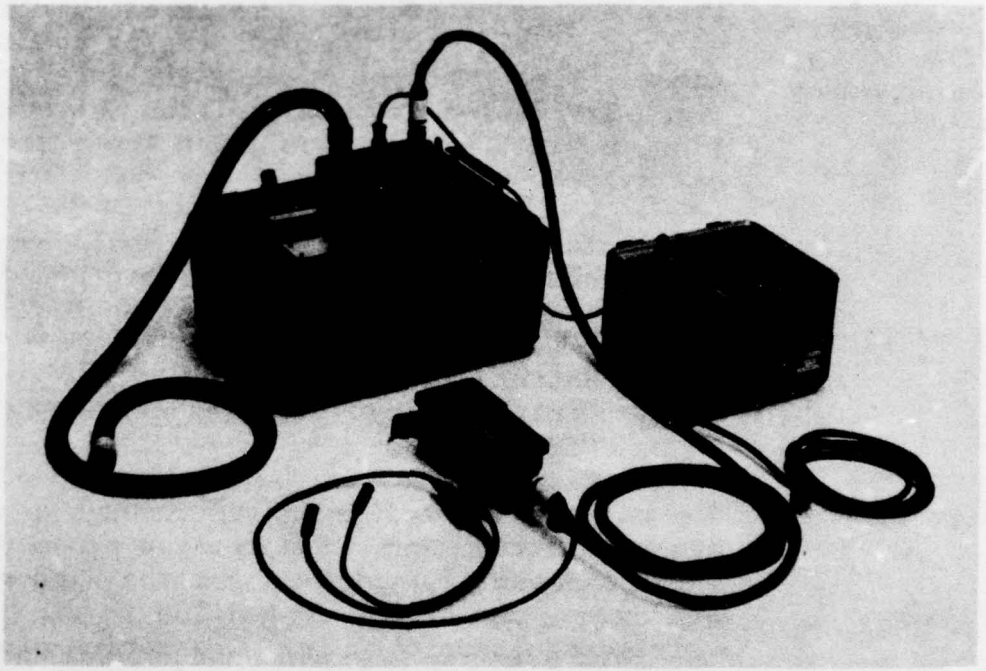

Figure 21-8. RCA's ATE/ICE Automotive Test System.

Description: ATE/ICE is a portable compact testing system which utilizes a stored program for service testing and fault diagnosis in an internal combustion engine. It consists of a transducer kit, a data processor with readout and hard copy capability, and an operator entry device. The major element, containing the data processor, is called the Programmable Diagnostic Unit (See Figure 21-8). The

ATE/ICE permits a real time interchange of information between the operator and the test equipment. Calibration data, test sequencing, and parameter limits are all part of the diagnostic program stored on magnetic cassette for execution by the unit's internal computer.

The testing procedure is based on the principle of introducing diagnostic routines only if normal operation does not meet certain predetermined standards. Tests are performed under "Idle" and "Loaded" engine conditions. The principal power plant subsystems which are tested include ignition, carburetion, engine (compression), and the electrical system.

Of special significance are the small number of transducers and attachments required for this system. Normal engine testing requires only the following four:

a. Battery Voltage
b. Igniter Probe
c. Firing Probe
d. Temperature

The battery voltage is sensed through a clamp-on attachment. The ignitor probe provides a capacitive pick-up for the high voltage output and direct connection to the low voltage ignition circuit. The firing probe is a simple attachment to the No. 1 cylinder spark plug and temperature probe is inserted in the engine in place of the oil dipstick. The system can also work with a diagnostic connector.

Three additional transducers are utilized only in cases which require additional testing. These are a clamp-on current probe and two pressure transducers. One of these senses intake manifold vacuum and the other blowby pressure.

In case of a NO START condition, the ATE/ICE initiates a special sequence of tests emphasizing the electrical aspects of the system.

The idle performance examines the RPM under idle conditions. In the case of incorrect or inconsistent RPM, the Idle Mixture Subroutine is initiated. The results of this operation are verified by repeating the Idle Performance Test. Subsequent tests of ignition performance involving automatic spark analysis can also be performed as required. Systematic ignition fault isolation is automatically initiated if the ignition test indicates a failure in this area. Cranking tests involve an analysis of the starter current which, in conjunction with timing obtained from the number one cylinder, provides an indication of the various cylinder compressions.

Engine performance under a virtually loaded condition is tested in a similar manner utilizing the previously described ignition interrupter principle. Engine tune-up and timing is also performed under direct ATE/ICE control.

21-1.9 Multi-Purpose Automatic Inspection and Diagnostic System (Programmed Testing System PTS-3116)

Manufacturer: Hamilton Test Systems, Incorporated, Subsidiary of United Technologies, Windsor Locks, Connecticut 06096/(203) 623-1621

Model: DEPOT MAIDS Figure No.: 21-9

Size:

Power Requirements:

National Stock No.:

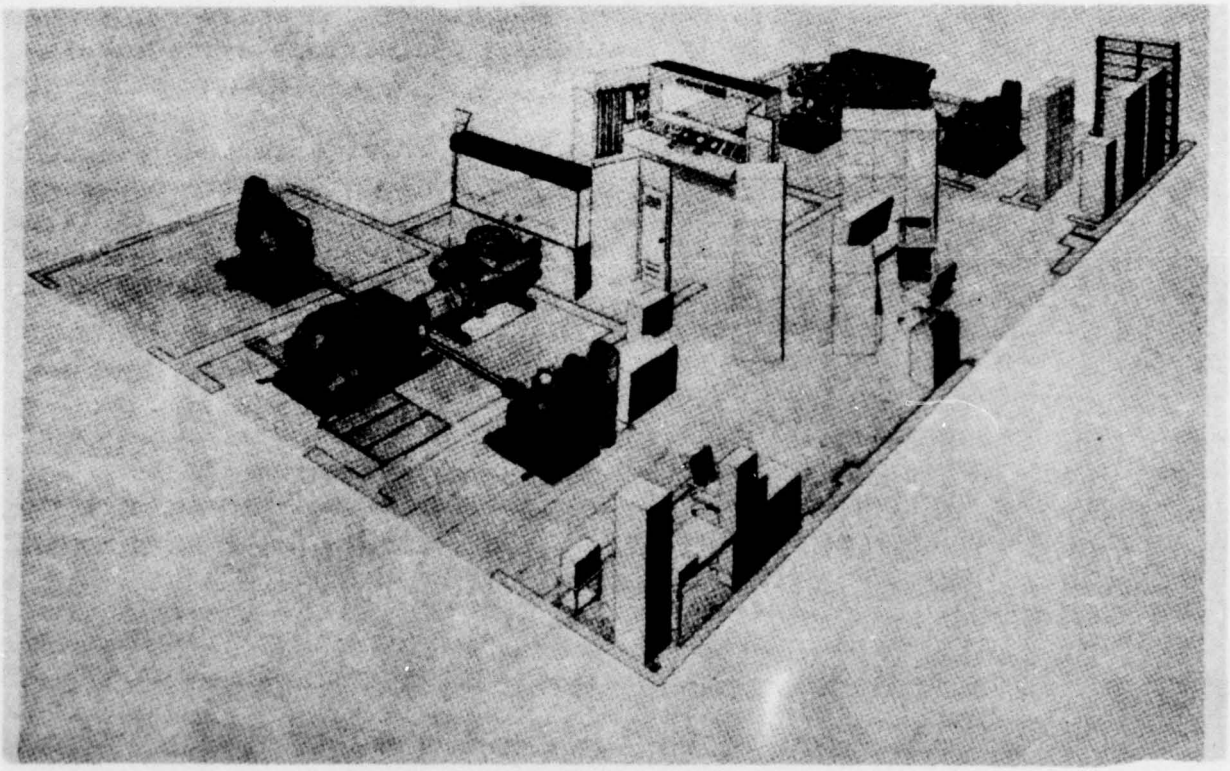

Figure 21-9. Hamilton Test System's PTS 3116, DEPOT MAIDS.

Description: The Depot MAIDS system is a multi-programmed computer controlled testing system for U.S. Army tracked-vehicle engine and engine/transmission power packs. It is implemented for

the purpose of providing an automatic diagnostic and run-in capability in order to achieve a more economical engine overhaul cost. Although the system was required to initially control automatic testing in two test cells at the Letterkenny Army Depot, Chambersburg, Pennsylvania, it was designed to allow for an orderly and logical expansion to include up to 13 test cells.

The system has three primary functions:

(1) To check incoming engines, identify engine faults, and thus identify those engines that need repair and those that need complete overhaul.

(2) Conduct automatic "run-in" and diagnosis of engines following repair or overhaul and pass or reject them.

(3) Prepare records on overhauled engines for future reference.

The system measures, for a typical diesel, 25 temperatures, 9 pressures, 18 vibrations, 7 flows, 3 speeds, and 1 current, position, torque, voltage and throttle position. It has successfully used time gate vibration analysis to determine valve and bearing problems.

The diagnostic capability for engines and power packs is principally a function of the various programmed analyses which are performed. These are starter current analysis, ignition analysis, injection analysis, intake and exhaust valve analysis, block vibration analysis and steady-state analysis. The results of the automatic diagnostic testing include a printout of engine and transmission malfunctions together with the logical data representing parts required to effect the necessary repair. The need to perform expensive teardown investigations is, therefore, eliminated due to the isolation and identification of specific malfunctions.

Run-in test of engines is programmed to include such elements as oil consumption tests, governor, blowby, and other performance tests. The log sheet produced by the automatic run-in includes all of the correct performance data at specific speeds pertaining to that test including horsepower calculations.

Figure 21-9 illustrates the system installed in the two-cell facilities at Letterkenny Army Depot. The system is installed in a master control room, test cell control room repair room and storeroom. In general, the master control room contains the master control console, logging typewriter, disc memory file, and six electronic equipment racks (two cabinets) enclosing the computer, electronics, various displays, built-in test equipment and test equipment patch panels. The master control console includes the computer controls, intercom, alphanumeric displays, teletypewriter and tape reader and punch. The test cell control rooms each contain a control console. Each console includes a throttle quadrant, set point controls, intercom, teletypewriter, and alphanumeric display. Testing is initiated and observed by the test cell operator. The displays in the master control room are for monitoring purposes only.

21-1.10 Autosense

Manufacturer: Hamilton Test Systems, Incorporated, Windsor Locks, Connecticut 06096/(203) 623-9974

Model: Autosense Figure No.: 21-10

Size: Weight:

Power Requirements:

National Stock No.:

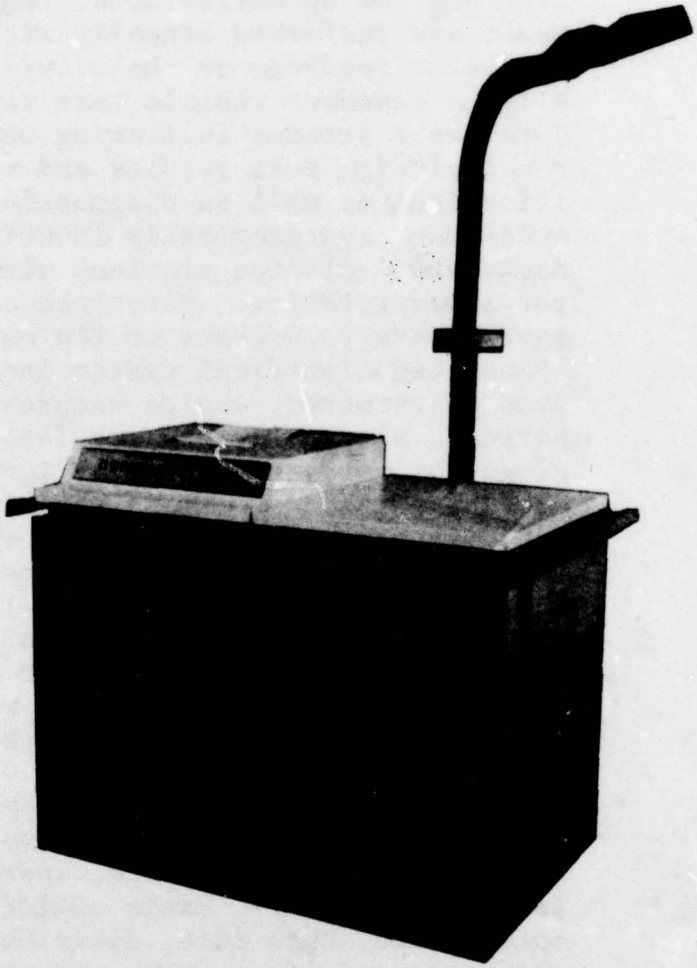

Figure 21-10. Hamilton Test Systems Autosense System.

Description: The Autosense system is a computer operated diagnostic equipment used for commercial fault isolation of spark ignition engines in vehicles. It consists of a console (Figure 21-10), hand held control, connector cable

and engine harness, and an optional exhaust emission analyzer. The Autosense system's computer program is stored on a tape cassette that also provides multi-year and model specification storage. The operator uses a hand held control with a keyboard and digital display to show test values as well as high and low specifications. Engine adjustments are performed manually with continuous parameter readings on the display. Additionally, a customer vehicle test report is produced on a printer indicating what tests were run including test results and vehicle specifications as well as diagnostic codes. Autosense systematically identifies repair needs and evaluates problems without operator interpretation. Autosense can perform approximately 70 tests on the engine and its associated electrical system including engine adjustments, engine compression, starter, battery, alternator and regulator, spark plugs, primary and secondary ignition, and exhaust omissions. Among the health, tune-up, diagnostic, running and no start checks made are the following: battery voltage, battery current drain, primary ignition current, coil primary voltage, distributor point voltage, started solenoid current, starter current, starter cable voltage drop, battery to relay voltage drop, starter control voltage, battery cranking voltage, battery to coil voltage drop, cranking RPM, engine rotation, coil available voltage, distributor rotor gap voltage, spark plug firing voltage, dwell, basic timing, relative compression, curb idle, distributor capacitor test, coil test, hydrocarbon content, carbon monoxide content, manifold vacuum, fast idle, cylinder power contribution, basic plus centrifugal advance, total timing, regulator battery voltage, alternator output voltage, alternator current, and spark plug load test.

21-1.11 Sun 2001 Diagnostic Computer

Manufacturer: Sun Electric Corporation, 3011 East Route 176, Crystal Lake, Illinois 60014/(815) 459-7700

Model: 2001 Figure No.: 21-11

Size: 64in. W x 25in. D x 43in. H Weight: 800lbs.

Power Requirements: 115 VAC, 60 Hz

National Stock No.:

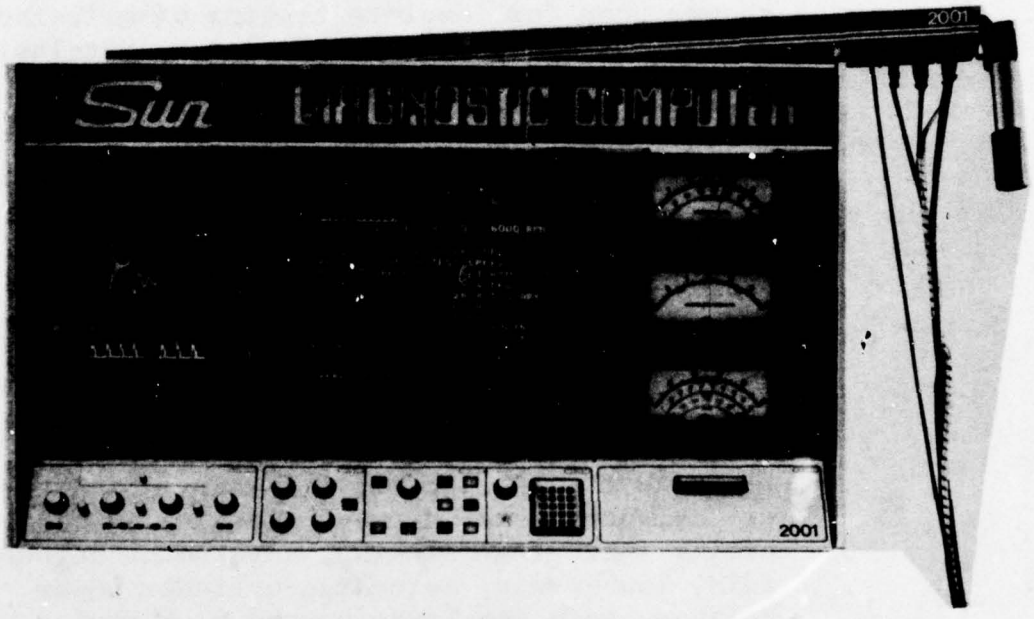

Figure 21-11. Sun Electric's 2001 Diagnostic Computer.

Description: Sun's 2001 diagnostic computer is an engine testing system that displays on a screen, in words and numbers - one test sequence at a time - the information a mechanic needs to completely diagnose and service an engine system. It delivers this information automatically - on command - from a remote control device operated by the mechanic.

The diagnostic computer incorporates two scope displays. The analog scope shown on the left side of Figure 21-11 can display desired cylinder waveforms and aid in the

diagnosis of alternator and fuel injection waveforms. The digital readout scope displays RPM in a linear fashion as well as test and test results data. The meters on the right side of the console provide vacuum, tachometer, dwell, leakage and pressure measurements.

The vacuum pressure meter has a built-in vacuum pump for complete testing of emission control systems. The bottom meter contains a tachometer and cylinder leakage scales. The tachometer and dwell units are switch-operated and read only when turned on. The cylinder leakage tester operates in the normal manner. All controls for the 3-gauge panel are contained in a flip-out drawer below. The timing light is a light, rugged new unit that puts maximum light on the timing marks. Timing advance for conventional and electromechanical timing is read on the center scope.

Seven test areas are built into the diagnostic computer's measurement and display capability including cranking, alternator output, idle, low cruise, automatic cylinder power balance, snap acceleration and high cruise. In addition, pinpoint test sample testing can be performed. In this mode, nine samples of specific parameters (e.g., Ignition - firing KV, dwell degrees, timing degrees, and cylinder timing) are displayed on the digital display for various speeds.

21-1.12 Integrated Diesel Engine Analyzer

Manufacturer: PRD Electronics, Harris Corporation, 6801 Jericho Turnpike, Syosset, New York 11791/ (516) 364-0400

Model: IDEA Figure No.: 21-12

Size: 20 in. W x 31 in. D x 46 in. H Weight: 200 lbs

Power Requirements: 115 VAC, 60 Hz, 600 Watts

National Stock No.:

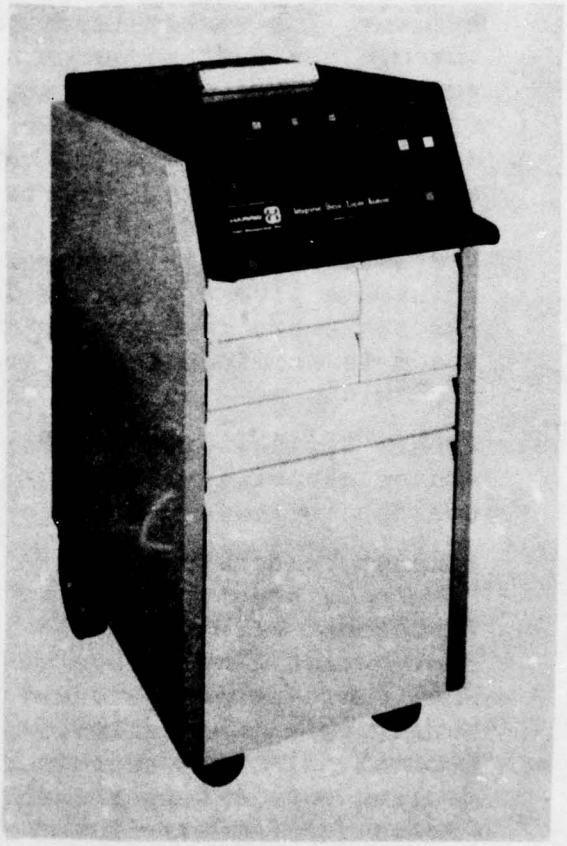

Figure 21-12. PRD's IDEA System.

Description: The IDEA system has been designed to test all existing diesel engines. It consists of a central processor controlled diagnostic unit with expandable memory, sensor/cable assembly, cassette tape reader, line printer and several indicators and controls. The system is referenced to normally operating, fault-

free engines. Cassette tape cartridges each of which contain the sequences required to troubleshoot several types of engines, provide the analyzer with the appropriate test program. IDEA then measures the critical parameters of a diesel's five systems: air, fuel, cooling, lubrication and basic engine, through sensors which primarily monitor pressure, temperature, vibration, engine speed and load. It detects symptoms (measurements outside prescribed tolerances), identifies faults and specifies the repair needed. The system leads the mechanic through the test sequence. It gives him continuous test run status, and tells what engine tests to run. Three flashing lights and an audible alarm indicate low oil pressures, high coolant temperature, and engine overspeed. The system is self-checking and has safeguards against operator error. IDFA's printouts give a complete log of every test run and every repair made to every diesel. Space is provided for engine serial number, mechanic's name and test date.

With a typical diesel under test, with full sensor capability, the IDEA system can monitor the following parameters:

Exhaust temperature
Crankcase pressure
Turboboost pressure
Fuel outlet temperature
Fuel pump suction pressure
Fuel supply pump outlet (manifold) pressure
Coolant inlet temperature
Coolant outlet temperature
Combustion (power) system
Brake horsepower
Coolant temperature rise
Blower pressure rise
Atmospheric pressure (not engine-mounted)
Ambient temperature (air-inlet)
Engine speed
Engine load (torque)
Lubrication oil pressure
Lubrication oil pressure
Piston cooling pressure

Air inlet temperature
Inlet air restriction pressure
Air box pressure.

21-1.13 Simplified Test Equipment for Internal Combustion Engines

Manufacturer: RCA, Automated Systems Division, P.O. Box 588, Burlington, Massachusetts 01803/(617) 272-4000

Model: STE/ICE (prototype) Figure No.: 21-13

Size: 7 in. H x 8.5 in. W x 11.5 in. D Weight: 11 lbs

Power Requirements: Any dc voltage between 8 and 32 volts

National Stock No.:

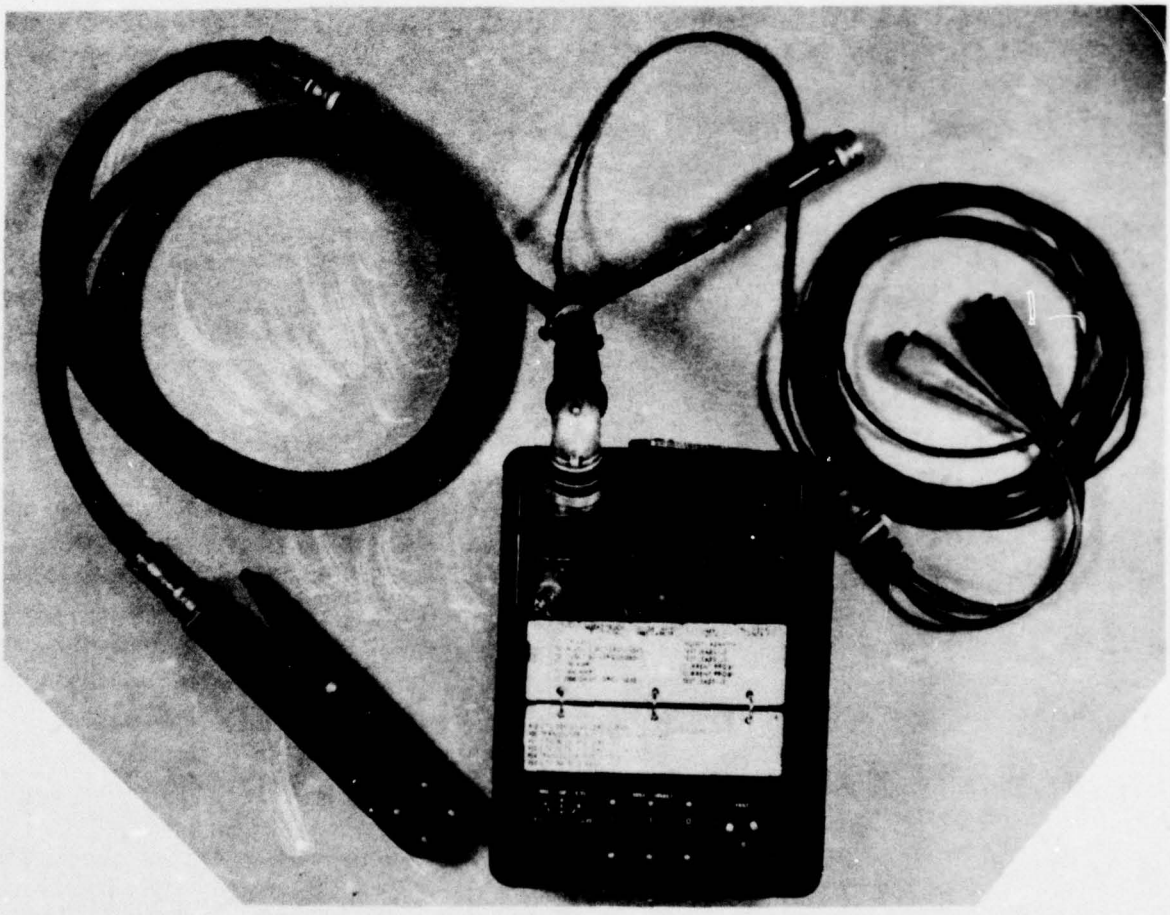

Figure 21-13. RCA's STE Automotive Test Equipment.

Description:

The STE/ICE system was designed to perform more than 70 tests and measurements on engine and accessory systems. In addition to measuring pressure, temperature, speed, voltage, and current, the system electronically performs a power test on gasoline and diesel engines without the need for an external dynamometer.

The STE/ICE system includes three major items of equipment: 1) the vehicle test meter (VTM), 2) a transducer kit, and 3) a diagnostic connector assembly. The first item is shown in Figure 21-13. The third item, built into the vehicles to be tested, includes pressure, temperature, and vacuum transducers, current shunts, and electrical connections. These are tied together by a system harness which brings all the test points to a conveniently mounted diagnostic connector. The VTM can make measurements using either the transducer kit or the diagnostic connector assembly. The pressure sensors used in the STE/ICE systems have solid-state sensing elements and have all the advantages of microcircuitry including small size, excellent repeatability and reliability, high output, low power, and high resistance to acceleration, vibration, and shock.

When the VTM is connected to a vehicle equipped with a diagnostic connector assembly, a mechanic can perform tests of engine power and compression, fuel/air, lubrication, cooling, ignition, starting, and charging systems in just a few minutes. The transducer kit is used on those vehicles which do not have a built-in diagnostic connector. The transducer kit's flexibility also allows it to be used as a supplement to the diagnostic connector tests by providing measurement capability for those parameters not implemented through the diagnostic connector transducers and test points.

A list of the tests which can be performed by STE/ICE is as follows:

Engine

Spark ignition (gasoline) power test
Compression ignition (diesel) power test
Compression balance
Engine r/min

Fuel/Air

Fuel supply pressure
Fuel return pressure
Fuel filter pressure drop
Air cleaner pressure drop
Turbocharger outlet pressure
Airbox pressure
Intake manifold vacuum
Intake manifold vacuum variation

Lubrication and Cooling

Oil pressure
Oil temperature
Coolant temperature

Starting/Charging

Battery voltage and current
Battery electrolyte level
Starter voltage and current
Starter current, first peak
Starter ground cable voltage drop
Alternator/generator output voltage and current
Alternator/generator field voltage and current

Ignition

Dwell angle
Points voltage
Coil primary voltage/resistance
Timing

To minimize training requirements, instruction cards integral to the meter are structured into test categories with the appropriate test numbers for input to the measurement select and test switches.

The VTM is capable of displaying numerics, words (PASS/FAIL, HI/LO) and simple key instructions or error messages to the mechanic.

21-1.14 Tem-pressure Engine Alarm and Shutdown System

Manufacturer: Kysor of Cadillac, 1100 Wright Street, Cadillac, Michigan 49601/(616)775-4681

Model: 9031 Series Figure No.: 21-14

Size: Weight:

Power Requirements: 12 VDC

National Stock No.:

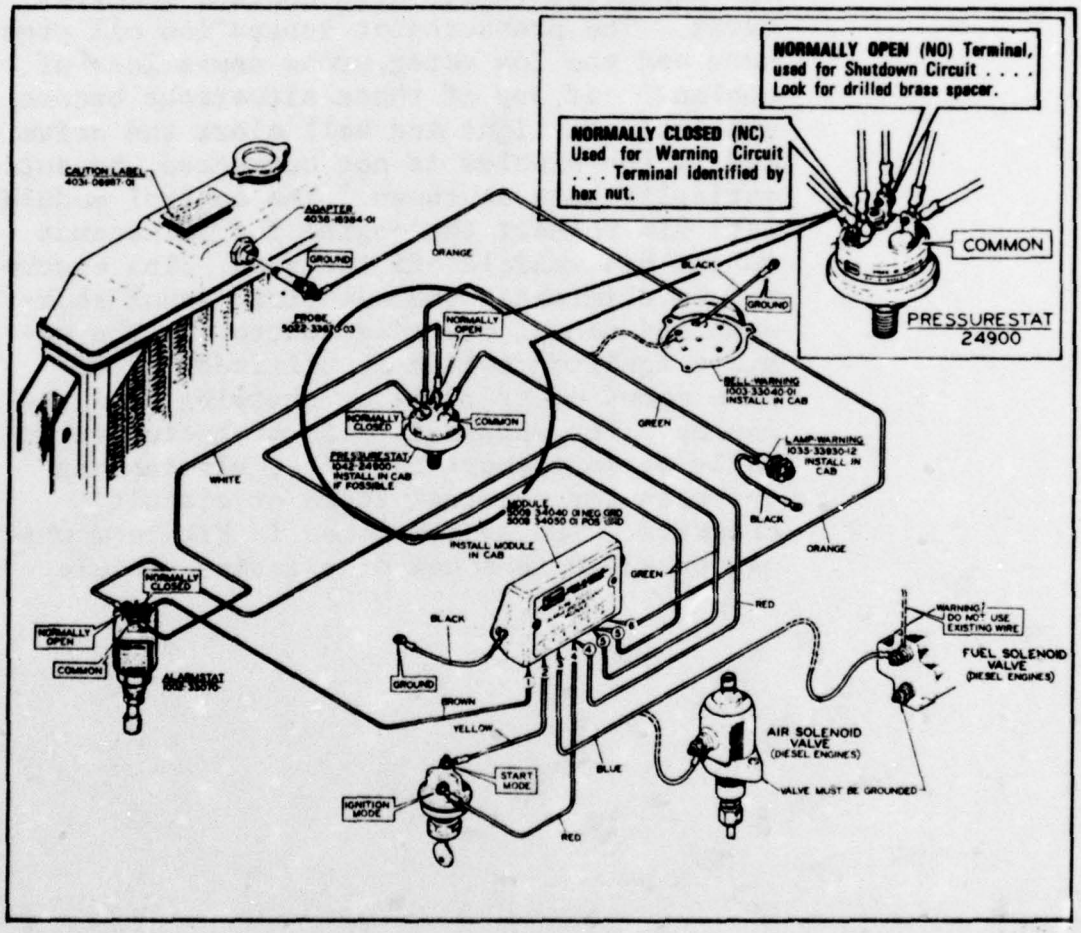

Figure 21-14. Installation Diagram for Kysor's Alarm and Shutdown System.

Description: The 9031 Tem-pressure system is an example of a simple monitoring system used to alert

an operator of impending greater engine damage. It consists of a control module, a coolant temperature sensor (Alarmstat), an oil pressure sensor (pressurestat), a low water coolant level probe, and an alarm bell/warning light.

The Tem-pressure system operates as follows: The alarmstat senses high coolant temperatures. The pressurestat senses low oil pressure and the low water probe sense loss of coolant. If any of these situations become critical the light and bell alert the driver and if the problem is not corrected, he automatically gets shutdown. The control module lets him restart the engine for 30 seconds to get his vehicle off the road. The control module eliminates the need for manual shutdown and manual override controls. The vehicle ignition switch is utilized as the sole means of starting or shutting down the engine. The module is also protected internally against short circuits, eliminating the need for external fuses or circuit breakers. The system comes in kit form which may be added to a new or existing vehicle.

GLOSSARY

The glossary of terms for this design guide is contained in three tables, G-1, G-2 and G-3. Table G-1 presents the definitions of maintainability terms used mainly in Parts I through IV. Table G-2 presents the definitions of technical terms used mainly in Parts IV through VI. Table G-3 contains the list of abbreviations and acronyms used in the design guide.

TABLE G-1. DEFINITIONS OF MAINTAINABILITY TERMS

The military standard for definition of maintainability terms is MIL-STD-721B. Refer to MIL-STD-721B for possible definition of terms not contained herein.

ACCESSIBILITY - The feature of design layout and installation which permits quick and easy admission (for performance of visual and manipulative maintenance) to the area in which a failure has been traced.

ACTIVE MAINTENANCE TIME - The time during which corrective or preventive maintenance is being done on an item.

ACTIVE REPAIR TIME - That portion of downtime during which one or more technicians are engaged in effecting the repair of a failed item.

ADJUSTMENT - The act of bringing any out-of-tolerance condition into tolerance by manipulating equipment adjustable features.

ADMINISTRATIVE AND SUPPLY TIME - The downtime due to nonavailability of spares, replacement parts, test equipment, or maintenance facilities, and the time due to nonavailability of maintenance technicians caused by administrative functions. Administrative and supply downtime is not part of active maintenance time.

ADMINISTRATIVE TIME - That portion of downtime not included in active repair time and logistic time.

ALLOCATED BASELINE - The initial approved allocated configuration identification (MIL-STD-480).

ALLOCATION - The process by which a top level quantitative requirement is allocated to lower hardware levels in relation to design characteristics, reliability, and maintainability features.

TABLE G-1. DEFINITIONS OF MAINTAINABILITY TERMS (Continued)

AUTOMATIC TEST EQUIPMENT (ATE) - Test equipment that contains provisions for automatically performing a series of preprogrammed tests.

AVAILABILITY - A measure of the conditions of an item at the start of a mission, when the mission is called for at an unknown (random) point in time.

BASELINE - A reference from which other system concepts are compared on the basis of relative merit in terms of qualitative or quantitative figures of merit.

CALENDAR TIME - The total number of calendar days or hours in a designated period of observations.

CAPABILITY - A measure of the ability of an item to achieve its objectives, given the item conditions during such achievement.

CLEANUP TIME - The time required to remove material used in connection with equipment maintenance (but not required for equipment operation).

COMPONENT - A combination of parts that cannot be disassembled in the field without invalidating functional integrity (e.g., valve, relay, actuator, gyro).

COMPREHENSIVENESS - The ratio of detected failures for which the value of the resolution stated holds true.

CONCEPT REVIEW - Review in which the operational support and hardware design concepts are analyzed for compatibility with system requirements.

CONFIDENCE INTERVAL - A range of values that is believed, with a preassigned level of confidence, to include the particular value of some parameter or characteristic being estimated.

CONFIDENCE LEVEL - The degree of confidence (expressed in percentage) in the performance or design of a system/equipment/hardware or accuracy of data.

CORRECTIVE MAINTENANCE - Actions performed, as a result of failure, to restore an item to a specified level of performance.

CORRECTIVE MAINTENANCE ACTION - Action required to repair a single failure; comprised of all those individual maintenance tasks involved in the maintenance procedure (e.g., fault localization, isolation, repair, checkout, etc.).

TABLE G-1. DEFINITIONS OF MAINTAINABILITY TERMS (Continued)

CORRELATION - The relationship between two (or more) variables, such that a change in one is accompanied by a change in the other.

CORRELATION COEFFICIENT - A number between -1 and +1 that indicates the degree of linear relationship between two sets of numbers.

COST EFFECTIVENESS - The relative value of a system determined by the ratio of the lowest possible total systems cost to actual system cost.

CRITICALITY - A subjective measure of the indispensability of an equipment or of the function performed by an equipment.

DEBUGGING - A process of "shakedown operation" of a finished equipment to identify and correct workmanship errors, defective parts, etc., which may have escaped the quality control inspection procedures.

DEMONSTRATION - An informal or formal procedure through which the maintainability characteristics, both qualitative and quantitative, of a system or item of equipment are illustrated through inspection, analysis, or test.

DENSITY FUNCTION - A mathematical function f(x) that, for discrete random variables, represents the probability that the value of the variable is x; for continuous random variables, f (x)dx represents the probability that the value of random varible is between x and x+dx.

DESIGN FREEZE - The finalization of system/equipment design for initial production.

DESIGN REVIEW - A detailed review, conducted at several points during the design phase, that provides an assessment of reliability, maintainability, and performance by the use of applicable tests and prediction techniques.

DIAGNOSTICS - The action required to identify the location of a fault to a lower level of hardware than that at which the fault was detected.

DOCUMENTATION - The recording of data required for the control of design, production, procurement, maintenance, and supply of material (e.g., drawings, specifications, handbooks, and manuals).

TABLE G-1. DEFINITIONS OF MAINTAINABILITY TERMS (Continued)

ENVIRONMENT - The external, physical, or circumstantial conditions that directly or indirectly affect the operation of a system, equipment, part, or other item under consideration.

EXPONENTIAL DISTRIBUTION - A one-parameter distribution used to characterize failures that occur randomly in time according to the density function $f(t) = \lambda \exp(-\lambda t)$.

FAILURE RATE - The average number of failures occurring per unit time in a specified time interval. Expressed as λ and equal to the reciprocal of mean time between failures (MTBF).

FAULT LOCATION - See DIAGNOSTICS.

FORMAL REVIEW - A review which is scheduled in the maintainability program plan; attendees at the review may include the procuring activity and/or its authorized representatives.

FREQUENCY-OF-USE PRINCIPLE (Equipment Design) - The principle of positioning the most frequently maintained items in preferred locations to facilitate maintenance.

FUNCTIONAL BASELINE - The initial approved functional configuration identification.

GENERATION BREAKDOWN - The classification of a system in terms of incremental hardware levels.

HARDWARE REVIEW - A review which determines whether or not individual hardware item designs adhere to their respective specification.

HUMAN FACTORS - Human psychological characteristics relative to complex systems, and the development and application of principles and procedures for accomplishing optimum man/machine integration and utilization.

INFORMAL REVIEW - A review which is conducted on a daily basis through daily liaison or in regular program (contractor) reviews and status meetings.

INTRINSIC AVAILABILITY - The probability that the system is operating satisfactorily at any point in time, where the time considered is operating time and active repair time.

ITEM - Any level of manufactured product such as a system, subsystem, equipment, assembly, subassembly, or part.

LIFE CYCLE COST - The total cost of acquisition, operation, maintenance, and support of an item throughout its useful life.

TABLE G-1. DEFINITIONS OF MAINTAINABILITY TERMS (Continued)

LOG NORMAL DISTRIBUTION - The probability distribution of a random variable whose logarithm is distributed normally.

LOGISTIC REQUIREMENTS - Those material requirements (tools, test equipment, spare parts, equipment, transportation, construction and operation of facilities, etc.) established as necessary to maintain or restore an item to an operational status, and the administrative procedures necessary to assure the stocking and delivery of these materials at the time of need.

LOGISTIC SUPPORT - The personnel and materials required by an item to ensure meeting its operational requirements, and the administrative and supply procedures necessary to assure availability of the personnel and materials when needed.

LOGISTIC TIME - That portion of downtime during which repair is delayed solely because of the necessity for waiting for a replacement part.

MAINTAINABILITY (M) - A characteristic of design and installation which is expressed as the probability that an item will be retained in or restored to a specific condition within a given period of time when the maintenance is performed in accordance with prescribed procedures and resources.

MAINTAINABILITY ANALYSIS - The formal procedure for evaluating system and equipment design, using prediction techniques, failure modes and effects, analysis procedures, and design data to evolve a comprehensive quantitative description of maintainability design status, problem areas, and corrective action requirements.

MAINTAINABILITY DEMONSTRATION - A test which demonstrates the degree of achievement of specified quantitative maintainability requirements.

MAINTAINABILITY GUIDELINES - The recommended course of action applied toward the accomplishment of the maintainability goal for a specific system or item of equipment.

MAINTAINABILITY PARAMETERS - A group of factors or environmental, human, and design features that affect the performance of maintenance on an equipment.

TABLE G-1. DEFINITIONS OF MAINTAINABILITY TERMS (Continued)

MAINTAINABILITY PREDICTION - The forecasting of quantitative maintainability characteristics of an item based on analyses of available information such as specifications, design guidelines, drawings, breadboard models, mockups, engineering models, pilot models, developed equipment, maintenance environment, and experience with similar items, depending on the availability of information at the time the prediction is made.

MAINTAINABILITY PROGRAM - A program in which maintainability is controlled throughout a system's life cycle by definition of the maintainability tasks to be performed and the management procedures that will be used.

MAINTAINABILITY PROGRAM PLAN - A description of the related time-phased tasks to be performed to implement the maintainability plan.

MAINTAINABILITY REQUIREMENT - A comprehensive statement of required maintenance characteristics (expressed in qualitative and quantitative terms) to be achieved in design and demonstrated in development.

MAINTAINABILITY TEST - See MAINTAINABILITY DEMONSTRATION.

MAINTENANCE ANALYSIS - The process of identifying required maintenance functions by analysis of the design to determine the most effective means to accomplish these functions.

MAINTENANCE CONCEPT - A description of the planned general scheme for maintenance and support of an item in the operational environment. The maintenance concept provides the practical basis for design, layout, and packaging of the system and its test equipment and establishes the scope of maintenance responsibility for each level of maintenance and the personnel resources required to maintain the system.

MAINTENANCE LEVEL - Division of maintenance, based on difficult and requisite technical skill, in which jobs are allocated to organizations in accordance with the availability of personnel, tools, supplies, and time within the organization.

MAINTENANCE PLAN - A document whose preparation begins at the start of a program and is available for the operational phase. The plan includes maintenance concepts, supply procedures, facilities requirements, levels of repair, user environment, and operational constraints.

MAINTENANCE PROCEDURES - Established methods for effecting repairs of items or for the periodic checking and servicing of items to prevent failure.

TABLE G-1. DEFINITIONS OF MAINTAINABILITY TERMS (Continued)

MAINTENANCE TIME - The time required to perform specified maintenance or the maintenance made necessary because of failure of the item concerned. Administrative time and supply time are excluded, but the following are included as appropriate to the specific maintenance task(s) involved: servicing time, inspection time, preparation time, access time, fault location time, item obtainment time, fault correction time, adjustment or calibration time, checkout time, cleanup time, and time required to replace worn parts (or scheduled part replacements) during preventive maintenance.

MALFUNCTION VERIFICATION TIME - The time spent testing or examining the system to observe previously reported symptoms of malfunction.

MATHEMATICAL MODEL - A representation of the significant cause-and effect relationships present in the real world, by means of mathematical expressions, numeric logic relationships, or other mathematical devices.

MEAN (Arithmetic Average) - The sum of a set of values divided by the total number comprising the set.

MEAN CORRECTIVE TIME ($\bar{M}_{ct}$) - The mean time required to complete a maintenance action. The total maintenance downtime divided by total maintenance actions. Synonomous with mean time to repair.

MEAN PREVENTIVE TIME ($\bar{M}_{pt}$) - The mean time required to perform scheduled preventive maintenance (PM) on an item, excluding PM time spent on equipment during operation.

MEAN TIME BETWEEN FAILURES (MTBF) - The total functioning life of a population of an item divided by the total number of failures within the population during the measurement interval.

MEDIAN MAINTENANCE TIME - The downtime within which 50 percent of all maintenance actions can be completed under the specified maintenance conditions. The median is expressed as $\tilde{M}_{ct}$ or M_{pt} depending on the maintenance action. In log normal distribution, the median is often expressed as geometric mean ($MTTR_G$) or equipment repair time (ERT).

MILESTONES - Any significant event in the design and development of an equipment item or in an associated program that is used as a control point for measuring progress and effectiveness or for planning or redirecting future effort.

MISSION - The specified role or operational requirement of a system or item of equipment.

TABLE G-1. DEFINITIONS OF MAINTAINABILITY TERMS (Continued)

MODULE - An organized group of parts complete in itself and capable of being handled as an entity. It is a preassembled element of the equipment to which it belongs and is installed or taken out of that equipment as an entity.

MONITORING - The continual checking of an equipment program to ensure that all phases of the program are satisfactorily implemented and continued throughout the duration of the program.

NORMAL DISTRIBUTION - A density function of a population that is bell shaped and symmetrical and is completely defined by two independent parameters: the mean and the standard deviation. The normal density function is:

$$f(t) = \frac{1}{\sigma 2\pi} e^{-\frac{(t-\mu)^2}{2\sigma^2}}$$

where:

σ = standard deviation
μ = mean
t = random variable in distribution

OPERATING TIME - The time period during which the material is performing its intended function.

OPERATIONAL AVAILABILITY FACTOR A(f) - An index used to judge the operational availability of electronic and electromechanical equipment, defined as:

$$A(f) = \frac{UT}{UT + DT}$$

where:

UT = total uptime
DT = total downtime

OPERATIONAL CONCEPT - The concept for the system or item of equipment which defines the manner in which the equipment will be used in its stated environment.

OPERATIONAL READINESS - The probability that at any moment an item is either operating satisfactorily or is ready to be placed in operation on demand when used under stated conditions.

PREDICTION - The process of which the maintainability characteristics, both qualitative and quantitative, are estimated for the system or item of equipment during its development.

TABLE G-1. DEFINITIONS OF MAINTAINABILITY TERMS (Continued)

PREDICTION TECHNIQUES - Methods for estimating the future behavior of an item on the basis of knowledge of its parts, functions, and operating environments, and the interrelationships of these factors.

PREVENTIVE MAINTENANCE - The composite of those maintenance actions performed on a periodic basis. The period may be based on calendar time, operating time, equipment cycles, etc.

PROCURING AGENCY - The activity that has the delegated authority in behalf of the U.S. Army to solicit and obtain supplies and services through contractual action.

PRODUCT BASELINE - The initial approved or conditionally approved product configuration identification.

PROTOTYPE - The first complete and working member of a class or series of an item intended to serve as the pattern or guide for subsequently produced members of the same class; a preproduction model suitable for complete evaluation of form, design, and performance.

QUALITY ASSURANCE PROGRAM - A planned and systematic pattern of all actions necessary to provide adequate confidence that the end items will perform satisfactorily in actual operation.

RELIABILITY - The probability that materiel and equipment will perform their intended function for a specified period under stated conditions.

REQUEST FOR PROPOSAL - A formal document prepared by the procuring agency and submitted to contractors for submittal of a proposal in relation to development or availability of a system, item, or equipment; normally designated as RFP.

RESOLUTION - The ratio of the average callout size to the system size on which the diagnostic system works. (The sizes expressed in the same dimension.)

SPECIFICATION - A formal document which states the requirements of a system or item of equipment in both qualitative and quantitative terms, and used for development or design.

STANDARD DEVIATION - A measure of the dispersion of values within a distribution and is indicated by the extent to which observed values of a variable tend to spread over an interval.

TABLE G-1. DEFINITIONS OF MAINTAINABILITY TERMS (Continued)

SUPPORT COST - The total cost of ownership, excluding operating crews and using personnel, of an item during its operational life, including the total impact of requirements for skill levels, technical data, test equipment, spares, spare parts, special tools, operational and maintenance equipment, facilities, levels and location of maintenance facilities, manpower, training, and training equipment.

SYSTEM - A combination of two or more subsystems, generally physically separated when in operation, and such other assemblies, subassemblies, and parts necessary to perform an operational function or function.

SYSTEM EFFECTIVENESS - A measure of the degree to which an equipment can be expected to achieve a set of specific mission requirements, and which may be expressed as a function of availability, dependability and capability.

SYSTEM LIFE CYCLE - That period of time which encompasses the initial inception of a system's operational requirements to a point in time where its useful life is terminated by obsolescence.

TEST ACCESSIBILITY - A built-in characteristic of equipment design and installation providing the means for connection, excitation, determination of operational condition, and malfunction diagnosis by test equipment.

TOTAL DOWNTIME - The portion of calendar time during which a system is not in condition to perform its intended function; includes active maintenance (preventive and corrective), supply downtime due to unavailability of needed items, and waiting an administrative time.

TRADE-OFF - The process by which one or more ways of accomplishing an objective are evaluated in respect to impact on design, support resources, and life cycle cost.

TABLE G-2. DEFINITIONS OF TECHNICAL TERMS

ACCUMULATOR - A fluid pressure storage chamber in which fluid pressure energy may be stored and from which it may be withdrawn.

BLADDER-TYPE - Hydropneumatic accumulator in which the liquid and gas are separated by an expandable bladder or elastic bag.

DIAPHRAGM-TYPE - A hydropneumatic accumulator in which the liquid and gas are separated by a flexible diaphragm.

NONSEPARATOR-TYPE - An accumulator in which a compressed gas operates directly upon the liquid in the pressure chamber.

PISTON-TYPE - An accumulator in which a compressed gas operates on a piston which applies force to the stored liquid.

SPRING-LOADED - An accumulator in which the compression energy is supplied by a spring.

WEIGHT-LOADED - An accumulator in which weights apply force to the stored liquid.

ACTUATOR - A device to convert fluid energy into mechanical motion.

ADDITIVE - A chemical compound or compounds added to a liquid to change its properties.

AUTOIGNITION TEMPERATURE (AIT) - The temperature at which a liquid placed on a heated surface will ignite spontaneously.

BOILING POINT - The temperature at which a fluid refluxes or distills under carefully specified conditions.

BULK MODULUS - The reciprocal of compressibility. It is usually expressed in pounds per square inch.

BYPASS - An alternate route which provides passage for a liquid around a component.

CAVITATION - A phenomenon of formation of cavities in a liquid across which the liquid can move with high velocity, producing a hammer effect on any object it strikes. It usually occurs where pressure is low and velocity high. Cavitation generally causes noise and damage to system components.

CENTIPOISE - A unit of absolute viscosity.

CENTISTOKE - A unit of kinematic viscosity.

CLOUD POINT - The temperature at which wax or other dissolved solids first precipitate during chilling under specified conditions.

TABLE G-2. DEFINITIONS OF TECHNICAL TERMS (Continued)

COEFFICIENT OF EXPANSION - The change in weight per unit volume per 1° change of temperature.

COMPRESSIBILITY - The reduction in volume of a liquid when pressure is applied. Compressibility is usually measured in terms of the bulk modulus, which is the reciprocal of compressibility.

CONTROL - A device used to regulate the functions of a component or system to which it is usually connected; may be integral or remote.

AUTOMATIC - A control actuated in response to a signal from the system; also a control which actuates equipment in a predetermined manner.

ELECTRIC - A control actuated by an electrical device.

HYDRAULIC - A control actuated by liquid pressure.

LIQUID-LEVEL - A device which controls the liquid level, such as a float switch.

MECHANICAL - A control actuated by linkages, cams, gears, screws, or other mechanical means.

PNEUMATIC - A control actuated by air or other gas pressure.

PUMP - Controls applied to hydraulic pumps to adjust their output or direction of flow.

SERVO - A control actuated by a feedback system which compares the output with the reference signal and makes corrections to reduce the difference.

CONDUCTION - Process by which heat flows from a region of higher temperature to a region of lower temperature within a medium or between different media in direct physical contact.

CONVECTION - Transference of heat by moving masses of fluid.

CYLINDER - A device for converting fluid energy into linear motion. It usually consists of a movable element such as a piston and piston rod, plunger or ram operating with a cylindrical bore.

DOUBLE-ACTING - A cylinder which moves in either direction due to fluid flow and pressure.

DOUBLE-END ROD - A cylinder with a single piston and with a rod extending from each end.

TABLE G-2. DEFINITIONS OF TECHNICAL TERMS (Continued)

PISTON-TYPE - A cylinder in which the movable element has a greater cross-sectional area than the piston rod.

PLUNGER-TYPE - A cylinder in which the movable element has the same cross-sectional area as the piston rod.

SINGLE-ACTING - A cylinder in which the fluid pressure is applied in only one direction.

SINGLE-END ROD - A cylinder with a rod extending from one end

DENSITY - The mass of a material occupying unit volume at a specified temperature. Its dimensions are mass per unit volume.

ELASTOMER - An elastic, rubber-like material.

EMULSION - An intimate dispersion of one liquid within another.

FILM STRENGTH - The ability of a liquid to maintain a film.

FILTER - A device through which a fluid is passed to separate material held in suspension. The filter medium is the material which removes the solids and consists of materials such as paper, cloth, finely woven screen, sintered metals, finely divided solids such as clay, activated charcoal, etc.

BYPASS - A filter which receives only a portion of the total fluid flow. Continuous mixing of the filtered and unfiltered fluid ensures that it is all eventually filtered in a reasonable period of time.

FIRE POINT - The temperature at which a liquid will burn continuously when ignited by a small flame under carefully specified conditions.

FIRE-RESISTANT FLUID - A fluid difficult to ignite and which shows little tendency to propagate flame.

FLASH POINT - The temperature at which a liquid gives off sufficient flammable vapors to ignite but not continue to burn when approached by a small flame under carefully specified conditions.

FLOW, LAMINAR - A flow situation in which motion occurs as a movement of one layer of fluid upon another. This is synonymous with streamline flow.

FLOW, STEADY STATE - A flow situation wherein conditions such as pressure, temperature, and velocity at every point in the fluid do not change.

TABLE G-2. DEFINITIONS OF TECHNICAL TERMS (Continued)

FLOW, STREAMLINE - A flow situation in which motion occurs as a movement of one layer of fluid upon another. This is synonymous with laminar flow.

FLOW, TURBULENT - A flow situation in which the liquid particles move in a random manner.

FLOW RATE - The unit volume of a fluid flowing per unit of time.

FLOW VELOCITY - The rate of speed at which a volume of fluid passes a particular point in a passage.

FLUID - A substance which yields to any pressure tending to alter its shape. Fluid, by strict definition, includes both liquid and gas.

HALOGENATED-TYPE - A fluid composed of halogenated organic materials and which may contain additional amounts of other constituents.

HYDRAULIC - A fluid suitable for use in hydraulic systems.

ORGANIC ESTER-TYPE - A fluid composed of esters of carbon, hydrogen, and oxygen, and which may contain additional amounts of other constituents.

PETROLEUM-TYPE - A fluid composed of petroleum hydrocarbons and which may contain additional amounts of other constituents.

PHOSPHATE ESTER-TYPE - A fluid composed of phosphate esters and which may contain additional amounts of other constituents.

POLYALKYLENE GLYCOL-TYPE - A fluid composed of polyalkylene glycols or derivatives and which may contain additional amounts of other constituents.

SILICATE ESTER-TYPE - A fluid composed of organic silicates and which may contain additional amounts of other constituents.

SILICON-TYPE - A fluid composed of silicones and which may contain additional amounts of other constituents.

SYNTHETIC - A material which, by definition, is nonpetroleum, but which may contain nonfunctional amounts of petroleum. Specifically, this permits petroleum to be used as a carrier for a constituent, i.e., for an additive, etc., but excludes petroleum used for any benefit of its properties per se.

TABLE G-2. DEFINITIONS OF TECHNICAL TERMS (Continued)

WATER-GLYCOL-TYPE - A fluid whose major constituents are water and one or more glycols or polyglycols and which may contain additonal amounts of other constituents.

WATER-OIL EMULSION TYPE - A stabilized emulsion of water-oil, and which may contain additional amounts of other constituents. There are two types: (1) oil-in-water, a conventional soluble oil in which oil is dispersed in a continuous phase of water, and (2) water-in-oil, a dispersion of water in a continuous phase of oil.

FLUID POWER - Power, transmitted and controlled through use of a pressurized fluid.

FLUID POWER SYSTEM - A system that transmits and controls power through use of a pressurized fluid within an enclosed circuit.

FOAM - An intimate mixture of gas and liquid occupying much more volume than the liquid alone.

FREEZING POINT - The temperature at which a fluid changes from liquid phase to solid phase.

FRICTION - Resistance to motion. Fluid friction is that friction due to the viscosity of the fluid.

HEAT EXCHANGER - A device for transferring heat from a hot fluid to a cold one, or reverse without the two coming in contact with each other. When used as a fluid cooler in a hydraulic system, it may take the form of either a nest of pipes in a suitable container, through which coolant flows, or a radiator.

HOSE - A flexible conduit for conveying fluid.

HYDRAULIC POWER SYSTEM - A means of energy transmission in which a relatively incompressible liquid (hydraulic fluid) is used as an energy-transmitting medium.

HYDROPNEUMATIC - The combination of hydraulic and pneumatic power in a unit.

INHIBITOR - Any substance which slows, prevents, or modifies chemical reactions such as corrosion or oxidation.

INTENSIFIER - A device which increases the working pressure over that delivered by a primary source. For example, such a device is one in which a low pressure acts on a large piston directly coupled to a smaller piston which then produces a higher pressure.

TABLE G-2. DEFINITIONS OF TECHNICAL TERMS (Continued)

ISENTROPIC - Having the same properties in all directions.

ISOTHERMAL - Describing a condition of constant temperature.

LEACHING - An operation in which the soluble component of a solid phase is dissolved and transferred to a liquid solvent.

MOTOR - A device for converting fluid energy into mechanical motion.

FIXED DISPLACEMENT - A rotary motor in which the displacement per revolution is fixed.

OSCILLATORY - A rotary actuator giving an angular movement of less than 360°, sometimes referred to as a rotary hydraulic actuator.

ROTARY - A motor producing continuous rotary motion.

VARIABLE DISPLACEMENT - A rotary motor in which the displacement per revolution is adjustable.

NEUTRALIZATION NUMBER - A measure of the acidity of basicity of a liquid. It is defined as milligrams of potassium hydroxide required to neutralize the acidity in one gram of fluid or the equivalent of the basicity expressed in a similar manner.

O-RING - An endless packing ring of circular cross section normally mounted in a groove in such a manner that the effectiveness of sealing increases with the pressure.

OXIDATION - A chemical reaction of oxygen with a liquid, resulting in the formation of oxidation products, which can cause changes in properties.

PACKING - Any material or device used to prevent leakage. Packings, seals, and gaskets are often considered synonymous.

PILOT LINE - A tube or hose which conducts control fluid.

PIPING - All pipe, tubing, hose, and fittings.

PISTON RING - A sealing ring which normally fits in grooves in the piston head.

POISE - The standard unit of absolute viscosity in the centimeter-gram-second system. It is expressed in dyne seconds per square centimeter.

PORT - An opening at a surface of a component, e.g., the terminus of a passage. It may be internal or external.

TABLE G-2. DEFINITIONS OF TECHNICAL TERMS (Continued)

POUR POINT - The lowest temperature at which a liquid will flow under specific conditions.

PRESSURE - Force per unit area. It is usually expressed in pounds per square inch.

ABSOLUTE - The sum of atmospheric and gage pressure.

ATMOSPHERIC - Pressure exerted by the atmosphere at any specific location. Sea level atmospheric pressure is approximately 14.7 psia.

OPERATING - The pressure at which a system is operated.

STATIC - The pressure that exists if there is no motion in the liquid.

SUCTION - The pressure of the liquid at the inlet of a pump.

PRESSURE DROP - The amount of pressure difference or the pressure required to force fluid through a component.

PRESSURE LOSS - The fall in pressure due to hydraulic friction in a component or circuit. Pressure losses at full flow are often appreciable; there is, however, none when flow ceases.

PUMP - A device which converts mechanical energy into fluid energy.

AXIAL PISTON CONSTANT VOLUME - A pump with a fixed volumetric output and with multiple pistons having their axis parallel to the drive shaft.

AXIAL PISTON VARIABLE VOLUME - An axial piston pump with an adjustable controlled volumetric output.

CENTRIFUGAL - A pump having an impeller rotating in a housing with liquid carried around the periphery of the housing and discharged by means of centrifugal force.

GEAR - pump having two or more intermeshing gears or lobed members enclosed in a suitably shaped housing.

RADIAL PISTON CONSTANT VOLUME - A pump with a fixed volumetric output having multiple pistons disposed radially.

RADIAL PISTON VARIABLE VOLUME - A radial piston pump with an adjustable volumetric output.

RECIPROCATING - A pump having reciprocating pistons to pressurize fluid.

TABLE G-2. DEFINITIONS OF TECHNICAL TERMS (Continued)

SCREW - A pump having one or more screws rotating in a housing.

TWO-STAGE - A pump with two separate pumping elements connected in a series. The primary stage may be used to ensure that the second main stage is not starved for fluid, or it may produce much of the pressure rise through the pump.

VANE, CONSTANT VOLUME - A pump having a fixed volumetric output with multiple vanes within a supporting rotor, encased in a cam ring.

VANE, VARIABLE VOLUME - A vane pump having suitable means of changing the volumetric output.

PUMP SLIPPAGE - Internal leakage in a pump from outlet to inlet side.

RADIATION - The process by which heat flows from a high-temperature body to a body at a lower temperature when the bodies are separated in space, even when a vacuum exists between them.

RESERVOIR - A container for fluid from which the fluid is withdrawn and returned after circulation through the system. The reservoir may be open to the atmosphere, or it may be closed and pressurized.

REYNOLDS NUMBER - A dimensionless number used in considerations of fluid flow and given by the formula: R_n = (Velocity) (pipe diameter)/Kinematic viscosity. When the Reynolds number is below 2000, laminar flow generally exists; at higher values, flow may be either laminar or turbulent, but the higher the value the less likely the flow will be laminar.

SEAL - A material or device designed to prevent leakage between parts, moving or static.

SERVOMECHANISM - Any mechanism which uses power magnification and in which there is incorporated a means of automatic correction of gross errors of the output.

SOLENOID - An electromagnet consisting of a wire-wound coil with a moving plunger which moves when the electric current is switched on.

SPECIFIC HEAT - The heat required to raise a unit weight one degree of temperature.

STABILITY - Resistance to permanent changes in properties under normal storage and use conditions.

TABLE G-2. DEFINITIONS OF TECHNICAL TERMS (Continued)

HYDROLYTIC - Resistance to permanent change in properties caused by chemical reaction with water.

OXIDATION - Resistance to permanent changes in properties caused by chemical reaction with oxygen.

THERMAL - Resistance to permanent changes in properties caused solely by heat.

STOKE - The standard unit of kinematic viscosity in the centimeter-gram-second system. It is expressed in square centimeters per second.

STRAINER - A filter made from wire mesh and capable of removing the larger particles of solids from a fluid.

SWITCH, PRESSURE - A switch operated by pressure and used for (a) controlling pressure between predetermined limits, (b) starting or stopping a sequence when a certain pressure is reached, and (c) as a safety device.

THERMOSTAT - A device for controlling temperature either by switching on and off an electric current or by opening and closing a valve in a liquid line.

TORQUE - Force applied through a rotary path of motion.

VACUUM - A pressure which is less than the prevailing atmospheric pressure.

VALVE - A device for controlling flow rate, direction of flow, or pressure of a liquid.

CAM-OPERATED - A valve in which the spool is positioned mechanically by a cam.

CHECK - A valve which permits flow of fluid in one direction only and self closes to prevent any flow in the opposite direction.

CLOSED CENTER - A valve which in the center position has all ports closed.

DIRECTIONAL - A valve whose primary function is to direct or prevent flow through selected passages.

FLOW CONTROL - A valve whose primary function is to control flow rate.

FLOW DIVIDING - A valve which divides the flow from a single source into two or more branches.

TABLE G-2. DEFINITIONS OF TECHNICAL TERMS (Continued)

FLOW DIVIDING, PRESSURE COMPENSATING TYPE - A valve which divides the flow from a single source into two or more branches at constant ratio, regardless of the difference in the resistances of the branches.

FOUR-WAY - A valve having four controlled working passages, usually ending in four external ports.

GATE - A valve with a gate which is raised or lowered by the action of a screw or other means to close or open the flow passage.

GLOBE - A valve with a plug, ball, or disc, which by action of a screw or other means, is pulled away from or lowered into a corresponding seat to open or close the flow passage.

NEEDLE - A valve with a tapered needle which is pulled away from or forced into a corresponding seat. The tapered needle permits gradual opening or closing of the passage.

OPEN CENTER - A valve which in the center position connects all ports.

PILOT - A valve applied to operate another valve or control.

PILOT-OPERATED - A valve in which operating parts are actuated by pilot fluid.

POPPET-TYPE - A valve construction which closes off flow by a poppet seating against a suitable seating material. Normally considered a dead-tight seal. The poppet may be a ball, a cone, or a flat disk.

PRESSURE REDUCING - A valve which maintains a reduced pressure at its outlet regardless of the higher inlet pressure or variations in flow.

RELIEF - A valve which opens when a set pressure is reached to prevent further rise of pressure in a system or to keep the pressure in a system or to keep the pressure constant. The relief valve limits pressure which can be applied to that portion of the circuit to which it is attached.

SEQUENCE - A valve which directs flow to a secondary portion of a fluid circuit in sequence. Flow is directed only to that part of the circuit which is connected to the primary or inlet port of the valve until the pressure setting of the valve is reached. At this time, the valve opens and pressure in the secondary port may vary from zero to near the setting of the primary side with no variation in the primary pressure.

TABLE G-2. DEFINITIONS OF TECHNICAL TERMS (Continued)

SHUTTLE - A connective valve which selects one of two or more circuits because flow or pressure changes between the circuits.

SOLENOID-OPERATED - A valve which is operated by one or more solenoids.

SPOOL-TYPE - A valve construction using a spool consisting of undercuts or recesses on a cylinder of metal. The spool is fitted in a bore containing annular undercuts. Movement of the spool in the bore connects ports uncovered by the spool undercuts.

THREE-POSITION - A valve having three positions to give three selection of flow conditions.

THREE-WAY - A directional control valve having three distinctive external working connections.

TWO-POSITION - A valve having two positions to give two selections of flow conditions.

TWO-WAY - A directional control valve having two distinctive external working connections.

UNLOADING - A valve which allows pressure to build up to an adjustable setting, then bypasses the flow as long as the preset pressure is maintained on the pilot port by a remote source. Its primary function is to unload a pump.

TIME DELAY - A valve in which the change to flow occurs only after a desired time interval has elapsed.

VAPOR PRESSURE - The pressure exerted by a fluid under consideration at a specified temperature.

VENTURI - local contraction in a pipe which is shaped so that the loss of total pressure due to friction is reduced to a minimum. As the velocity increases at the Venturi throat, the static pressure decreases appreciably. Venturi tubes are often used as flow meters, the difference of pressure between the entrance to the Venturi and the throat varying as the square of flow.

VISCOMETER - A device for measuring viscosity.

VISCOSITY - A measure of the internal friction or the resistance of a fluid to flow.

TABLE G-2. DEFINITIONS OF TECHNICAL TERMS (Continued)

ABSOLUTE - The force required to move a plane surface over another plane surface at the rate of one centimeter per second when the surfaces are one centimeter square and are separated by a layer of fluid one centimeter in thickness. This force is known as the poise.

KINEMATIC - The ratio of absolute viscosity to the density of a fluid. The unit of kinematic viscosity is the stoke. Viscosity in stokes, multipled by density at the test temperature equals the absolute viscosity in poise.

SAYBOLT UNIVERSAL SECONDS (SUS) - Saybolt Universal Second viscosity is the time in seconds required for 60 cc of liquid to flow through a standard orifice at a given temperature.

VISCOSITY INDEX (V.I.) - A measure of the viscosity-temperature characteristics of a fluid as referred to that of other fluids.

VOLATILITY - The property of a fluid describing the degree to which it will vaporize under given conditions of temperature and pressure.

TABLE G-3. ABBREVIATIONS/ACRONYMS

- A -

AC	-	Alternating Current
AD	-	Advanced Development
A/D	-	Analog to Digital (Converter)
ADO	-	Advanced Development Objectives
ADP	-	Automatic Data Processing
ADPE	-	Automatic Data Processing Equipment
AEG	-	Active Element Group (component of an SRA)
AFG	-	Army Force Guidance
AGE	-	Aerospace Ground Equipment
ALRTF	-	Army Long Range Technological Forecast
AMC	-	Army Materiel Command (Renamed DARCOM)
AMFD	-	Army Master Data File
AMMC	-	Army Maintenance Management Center
AMMH	-	Annual Maintenance Man Hours
AMRDL	-	U.S. Army Air Mobility Research and Development Laboratory
AOP	-	Additative Operational Project
AP	-	Advance Procurement
APBI	-	Advanced Planning Briefing for Industry
APE	-	Advanced Production Engineering
APM	-	Army Program Memorandum
APP	-	Army Procurement Procedures
APU	-	Auxiliary Power Unit
AR	-	Army Regulation
ARMCOM	-	U.S. Armament Command
ARNG	-	Army National Guard
ASA	-	U.S. Army Security Agency
ASA	-	Army Strategic Assessment
ASARC	-	Army Systems Acquisition Review Council
ASCP	-	Army Strategic Capabilities Plan
ASPR	-	Armed Services Procurement Regulation
ASTM	-	American Standards for Testing Material
ATC	-	Army Training Center
ATE	-	Automatic Test Equipment
ATLAS	-	Abbreviated Test Language for Avionic Systems
ATP	-	Army Training Program
ATT	-	Army Training Test
AUTODIN	-	Automatic Digital Network
AVIM	-	Aviation Intermediate Support Maintenance
AVSCOM	-	U.S. Army Aviation Systems Command
AVUM	-	Aviation Unit Maintenance

TABLE G-3. ABBREVIATIONS/ACRONYMS (Continued)

- B -

BB	-	Building Block
BCE	-	Baseline Cost Estimate
BIIL	-	Basic Issue Items List
BIT	-	Built-In Test
BITE	-	Built-In Test Equipment
BOI	-	Basis of Issue
BOIP	-	Basis of Issue Plan
BRA	-	Bench Replaceable Assembly (a form of SRA)
BTA	-	Best Technical Approach
BY	-	Budget Year

- C -

C&T	-	Contingency and Training
CAA	-	Concepts Analysis Agency
CAIG	-	Cost Analysis Improvement Group
CARDS	-	Catalog of Approved Requirements Documents
CBU	-	Calibration Before Use
CCE	-	Commercial Construction Equipment
CD	-	Combat Developer
CDOG	-	Cambat Developments Objective Guide
CDRL	-	Contract Data Requirements List
CF	-	Concept Feasibility
CFE	-	Contractor Furnished Equipment
CFP	-	Concept Formulation Package
CFY	-	Current Fiscal Year
CG	-	Center of Gravity
CM	-	Configuration Management
CNDI	-	Commercial Non-Developmental Item
CNR	-	Calibration Not Required
CO	-	Commanding Officer
COA	-	Comptroller of the Army
COEA	-	Cost and Operational Effectiveness Analysis
COMSEC	-	Communications Security
CON	-	Contingency
CONUS	-	Continental United States
CPIF	-	Cost Plus Incentive Fee
CPU	-	Central Processing Unit
CRDA	-	Chief of Research, Development and Acquisition
CRT	-	Cathode Ray Tube
CSA	-	Chief of Staff, U.S. Army
CTA	-	Common Table of Allowance
CTP	-	Coordinated Test Program
CW	-	Chemical Warfare
CY	-	Calendar Year

TABLE G-3. ABBREVIATIONS/ACRONYMS (Continued)

- D -

D&F	-	Determination and Findings
d	-	Diameter
DA	-	Department of the Army
DAMWO	-	Department of the Army Modification Work Order
DARCOM	-	Development And Readiness Command
db	-	Decibels
dc	-	Direct Current
DCP	-	Development Concept Paper
DCP	-	Decision Coordinating Paper
DCS	-	Defense Communications System
DCSLOG	-	Deputy Chief of Staff for Logistics
DCSOPS	-	Deputy Chief of Staff or Military Operations and Plans
DCSPER	-	Deputy Chief of Staff for Personnel
DCSRDA	-	Deputy Chief of Staff, Research, Development and Acquisition
DD	-	Defense Department
DDC	-	Defense Documentation Center
DDRE	-	Director of Defense Research and Engineering
DEPSECDEF	-	Deputy Secretary of Defense
DEVA	-	Development Acceptance
DFC	-	Diagnostic Flow Chart
DID	-	Data Item Description
DOD	-	Department of Defense
DODAAC	-	Department of Defense Activity Address Code
DODD	-	Department of Defense Directive
DODI	-	Department of Defense Instruction
DODIC	-	Department of Defense Identification Code
DP	-	Development Plan
DPM	-	Defense Program Memorandum
DPMN	-	Draft Proposed Materiel Need
DPMN (ED)	-	Draft Proposed Materiel Need
DRIF	-	Defense Railroad Interchange Fleet
DS	-	Direct Support
DSARC	-	Defense Systems Acquisition Review Council
DT	-	Development Training
DT	-	(I, II, III) - Development Test (I, II, III)
DTC	-	Design to Cost
DX	-	Direct Exchange

TABLE G-3. ABBREVIATIONS/ACRONYMS (Continued)

- E -

ECC	-	Equipment Category Code
ECOM	-	United States Army Electronics Command
ED	-	Engineering Design
ED	-	Engineering Development
EDP	-	Electronic Data Processing
EFC	-	Equivalent Full Charge
EGT	-	Exhaust Gas Temperature
EIMIF	-	End Item Master Identification File
EIR	-	Equipment improvement recommendations; equipment improvement reports
EL	-	Electro-Luminescent
ELP	-	English Language Program
EMC	-	Electro-Magnetic Compatibility
EMD	-	Electric Motor Drive
EML	-	Equipment Maintenance Log
EOC	-	Elementary Operations Controller
EOD	-	Explosive Ordnance Disposal
ESC	-	Equipment Serviceability Criteria
EW	-	Electronic Warfare

- F -

FDTE	-	Force Development Test and Experimentation
FGC	-	Functional Group Code
FM	-	Field Manual
FM	-	Frequency Modulation
FMEA	-	Failure Modes and Effects Analysis
FOD	-	Foreign Object Damage
FORTRAN	-	Formula Translation
FRA	-	Federal Railways Administration
FSC	-	Federal Stock Class
FSN	-	Federal Stock Number
FTA	-	Fault Tree Analysis
FY	-	Fiscal Year

- G -

GFAE	-	Government Furnished Aeronautical Equipment
GFE	-	Government Furnished Equipment
GFM	-	Government Furnished Material
GP	-	General Purpose
GPM	-	Gallons Per Minute
GS	-	General Support
GSE	-	Ground Support Equipment

TABLE G-3. ABBREVIATIONS/ACRONYMS (Continued)

- H -

HQDA	-	Headquarters, Department of the Army
HZ	-	Hertz

- I -

ICE	-	Internal Combustion Engine
ICP	-	Inventory Control Point
ID	-	Interconnection Device
IDPNM	-	Initial Draft Proposed Materiel Need
IER	-	Independent Evaluation Report
ILS	-	Integrated Logistic Support
ILSP	-	Integrated Logistic Support Plan
IOC	-	Initial Operational Capability (date)
IPCE	-	Independent Parametric Cost Estimate
IPF	-	Initial Production Facilities
IPR	-	In-Process Review
IPRA	-	In-Place Repairable Assembly
IR&D	-	Independent Research and Development

- J -

JAN	-	Joint Army-Navy
JSOR	-	Joint Service Operational
JTA	-	Joint Table of Allowance
JWG	-	Joint Working Group

- K -

KAO	-	Cryptographic Aids Operating Instructions

- L -

LCMM	-	Life Cycle Management Model
LEA	-	Logistics Evaluation Agency
LIN	-	Line Item Number
LO	-	Lubrication Order
LOA	-	Letter of Agreement
LOI	-	Letter of Instruction
LP	-	Limited Procurement
LR	-	Letter Requirement
LRA	-	Light Replaceable Assembly
LRU	-	Line Replaceable Unit
LSA	-	Logistic Support Analysis
LSAR	-	Logistic Support Analysis Record
LSP	-	Logistic Support Plan

TABLE G-3. ABBREVIATIONS/ACRONYMS (Continued)

		- M -
M/A	-	Maintainability and Accessibility
MAC	-	Maintenance Allocation Chart
MACRIT	-	Manpower Authorization Criteria
MADP	-	Materiel Acquisition and Decision Process
MAIT	-	Maintenance Assistance and Instruction Team
MAP	-	Military Assistance Program
MD	-	Materiel Developer
MDS	-	Mission, Design, Series
MERDC	-	U.S. Army Mobility Equipment Research and Development Center
MICOM	-	United States Army Missile Command
MILPERCEN	-	Military Personnel Center
MIL STD	-	Military Standard
MILSTRIP	-	Military Standard Requisitioning and Issue Procedures
MMT	-	Manufacturing Methods and Technology
MN	-	Materiel Need
MN (A)	-	Materiel Need (Abbreviated)
MN (ED)	-	Materiel Need (Engineering Development)
MN (P)	-	Materiel Need (Production)
MN (PI)	-	Materiel Need (Product Improvement)
MN (TP)	-	Materiel Need with Technical Plan
MOC	-	Maintenance Operation Check
MOS	-	Military Occupational Specialty
MSO	-	Materiel Status Office
MSR	-	Missile Site Radar
MTBF	-	Mean Time Between Failures
MTDA	-	Modification Table of Distribution and Allowances
MTOE	-	Modification Table of Organization and Equipment
MTMTS	-	Military Traffic Management and Terminal Services
MTTR	-	Mean Time To Repair
MWO	-	Modification Work Order
		- N -
NCOIC	-	Noncommissioned Officer In Charge
NET	-	New Equipment Training
NICP	-	National Inventory Control Point
NMP	-	National Maintenance Point
NOR	-	Not Operationally Ready
NORM	-	Not Operationally Ready, Maintenance
NORS	-	Not Operationally Ready, Supply
NRTS	-	Not Repairable This Station

TABLE G-3. ABBREVIATIONS/ACRONYMS (Continued)

		- N -
NSIA	-	National Security Industrial Association
NSN	-	National Stock Number
NTIS	-	National Technical Information Service
		- O -
OASD (I&L)	-	Office, Assistant Secretary of Defense (Installations and Logistics)
OB	-	Obsolete
OCO	-	Officer In Charge
OCRDA	-	Office of the Chief of Research, Development and Acquisition
ODCSRDA	-	Office, Deputy Chief of Staff, Research, Development, and Acquisition
ODP	-	Outline Development Plan
OEM	-	Original Equipment Manufacturer
OIC	-	Officer In Charge
OMA	-	Operations and Maintenance, Army
OMB	-	Office of Management and Budget
OPAL	-	Operational Performance Analysis Language
OR	-	Operationally Ready
OR	-	Operations Research
ORF	-	Operational Readiness Float
OSA	-	Office, Secretary of the Army
OSD	-	Office of the Secretary of Defense
OT	-	(I, II, III) - Operational Testing (I, II, III)
OTE	-	Operational Test and Evaluation
OTEA	-	Operational Test and Evaluation Agency
		- P -
PAR	-	Perimeter Acquisition Radar
PCW	-	Previously Complied With
PD	-	Priority Designator (formerly Issue Priority Designator (IPD))
PDD	-	Program Design Document
PDM	-	Program Decision Memorandum
PDO	-	Property Disposal Officer
PDU	-	Programmable Diagnostic Unit
PEMA	-	Procurement, Equipment and Munitions Army
PEP	-	Producibility Engineering and Planning
PHST	-	Packaging, Handling, Storage and Transportability
PI	-	Product Improvement
PIP	-	Product Improvement Program

TABLE G-3. ABBREVIATIONS/ACRONYMS (Continued)

		- P -
PIP	-	Product Improvement Proposal
PLT	-	Program Library Tape
PMD	-	Preventive Maintenance, Daily
PMI	-	Preventive Maintenance, Intermediate
PMN	-	Proposed Materiel Need
PNM (ED)	-	Proposed Materiel Need (Engineering Development)
PMN (TP)	-	Proposed Materiel Need with Technical Plan
PMO	-	Project Management Office
PMP	-	Preventive Maintenance, Periodic; Project Master Plan
PMS	-	Preventive Maintenance Services
POI	-	Program(s) Of Instruction
POM	-	Program Objective Memorandum
P&P	-	Procurement and Production
PQQPRI	-	Provisional Qualitative and Quantitative Personnel Requirements Information
PS	-	Power Supply
PSI	-	Pounds Per Square Inch
PV	-	Production Validation
PVC	-	Positive Ventilation Crankcase
		- Q -
QA	-	Quality Assurance
QCR	-	Qualitative Construction Requirement
QMDO	-	Qualitative Materiel Development Objectives
QMR	-	Qualitative Materiel Requirements
QQPRI	-	Qualitative and Quantitative Personnel Requirements Information
QRA	-	Quick Replaceable Assembly
QRI	-	Qualitative Materiel Requirements
QRR	-	Qualitative Research Requirement
QSS	-	Quick Supply Service
		- R -
R&D	-	Research and Development
R&M	-	Reliability and Maintainability
R&U	-	Repairs and Utilities
RADIAC	-	Radiation, Detection, Indication and Computation
RAM	-	Reliability, Availability, Maintainability
RDTE	-	Research, Development, Test and Evaluation
RFP	-	Request for Proposal
RFQ	-	Request for Quotation
RICC	-	Reportable Item Control Code
RMA	-	Reliability, Maintainability, and Availability

TABLE G-3. ABBREVIATIONS/ACRONYMS (Continued)

- R -

RMS	-	Resource Management System
rms	-	Root Mean Square
ROC	-	Required Operational Capability
rpm	-	Revolutions per minute

- S -

SA	-	Secretary of Army
SACS	-	Structure and Composition System
SAG	-	Study Advisory Group
SAMS	-	Standard Army Maintenance System
SAS	-	Stability Augmentation System
SB	-	Supply Bulletin
SC	-	Signal Conditioner
SDC	-	Sample Data Collection
SDR	-	Small Development Requirements
SE	-	Support and Test Equipment
SEA	-	Southeast Asia
SECDEF	-	Secretary of Defense
SIGINT	-	Signal Intelligence
SIMU	-	Suspended from Issue, Movement and Use
SIU	-	Suspended from Issues and Use
SMR	-	Source, Maintenance and Recoverability
SOP	-	Standing Operating Procedure
SP	-	Special Purpose
SRA	-	Shop Replaceable Assembly
SSE	-	Special Support Equipment
SSG	-	Special Study Group
SSP	-	System Safety Program
SSS	-	Self Service Supply
STF	-	Special Task Force
STD	-	Standard

- T -

TA	-	Table of Allowance
TA	-	Test Agency
TAADS	-	The Army Authorization Documents System
TACOM	-	United States Army Tank-Automotive Command
TAERS	-	The Army Equipment Record System
TAG	-	The Adjutant General
TAGO	-	The Adjutant General's Office
TAMMS	-	The Army Maintenance Management System
TB	-	Technical Bulletin
TBO	-	Time Between Overhaul

TABLE G-3. ABBREVIATIONS/ACRONYMS (Continued)

TBOIP	-	Tentative Basis of Issue Plan
TC	-	Type Classifications
TD	-	Table(s) Distribution
TD	-	Test Diagrams
TDA	-	Tables of Distribution and Allowances
TDR	-	Training Device Requirement
TDY	-	Temporary duty
T&E	-	Test and Evaluation
TEAC	-	Turbine Engine Analysis Check
TILO	-	Technical Industrial Liaison Office
TIT	-	Turbine Inlet Temperature
TK	-	Transducer Kit
TM	-	Technical Manual
TMA	-	Test Methods Analysis
TMDE	-	Test, Measuring and Diagnostic Equipment
TMOS	-	Tentative Military Occupational Speciality
TMS	-	Type, Model, Series
TOA	-	Trade-Off Analysis
TOD	-	Trade-Off Determination
TOE	-	Table(s) of Organization and Equipment
TPB	-	Test Program Booklet
TRA	-	Test Requirements Analysis
TRADOC	-	U.S. Army Training and Doctrine Command
TTY	-	Teletype Unit
TWX	-	Teletypewriter Exchange (commercial)
TY	-	Target Year
		- U -
UIC	-	Unit Identification Code
USACC	-	United States Army Communications Command
USAF	-	United States Air Force
USAMC	-	United States Army Materiel Command (Renamed DARCOM)
USAMMC	-	United States Army Maintenance Management Center
USAR	-	United States Army Reserve
USATRADOC	-	United States Army Training and Doctrine Command
USC	-	United States Code
UUT	-	Unit Under Test
		- V -
VA	-	Validation
VAL	-	Validation
VCSA	-	Vice Chief of Staff Army
VE	-	Velocity Error
VOCO	-	Verbal Orders of Commanding Officer

TABLE G-3. ABBREVIATIONS/ACRONYMS (Continued)

- W -	
WBS	Work Breakdown Structure
WRA	Weapons Replaceable Assembly
WUC	Work Unit Code

REFERENCES

1. MIL-STD-721B, Definitions of Effectiveness Terms for Reliabbility, Maintainability, Human Factors, and Safety .

2. MIL-STD-1309B, Definitions of Terms for Test, Measurement and Diagnostic Equipment.

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